IJE TRANSACTIONS B: Applications Vol. 31, No. 5, (May 2018) 841-846

International Journal of Engineering

Journal Homepage: www.ije.ir

Effect of Ambient Condition on the Shower Cooling Tower in Four Type of Climates Condition

A. Asghari[a], N. Kordani*[b]

[a] Faculty of Mechanical Engineering, Islamic Azad University, Noor Branch
[b] Faculty of Mechanical Engineering, University of Mazandaran, Babolsar, Iran

PAPER INFO

Paper history:
Received 13March 2017
Received in revised form 13January 2018
Accepted 14February2018

Keywords:
Shower Cooling Tower
Heat Transfer
Mass Transfer

ABSTRACT

Water cooling by ambient takes place with two mechanisms of heat and mass transfer. Using packings at wet cooling towers has disadvantages such as obstruction, reduction of life expectancy and production of algae and fungi. In shower cooling towers types of towers packings are completely removed and water intake is in direct contact and heat transfer takes place in two ways of latent and sensible. In this article mathematical modeling and simulation of towers has been done using differential equations. Differential equations derived using the laws of conservation of mass and energy. Differential equations is solved in a computer program for numerical solution. The operation of shower cooling towers at different environmental conditions was observed. These towers in the area of cold, dry, warm and dry possess high efficiency. In very hot areas by reducing the drops diameter, the tower outlet temperature can be improved.

doi: *10.5829/ije.2018.31.05b.21*

NOMENCLATURE

G_d	Forces gravity (N)	A_d	Droplet cross section area (m2)
F_d	Buoyancy from the air	h_c	Heat transfer coffitiont
R_d	Resistance from the air	h_d	Mass transfer coffitiont
g	Gravity(m/s^2)	U_d	Vertical droplet velocity (m/s)
d	Droplet diameter	U_a	Vertical air velocity (m/s)
H	tower height (m)	m_d	Droplet mass (kg)
dz	Thickness of element(m)	W_a	Air humidity
i_w	air enthalpy	W_{Tw}	Humidity at the saturated temperature
i_{ma}	mixture of water and air enthalpy	T_w	Water temperature (c)
dQc	Sensible heat	T_a	Air temperature (c)
dQe	Latent heat	C_{pa}	Specific heat of dry air
i_{masw}	Saturated enthalpy at ambient temperature	**Greek Symbols**	
cd	Drag coefficient	ρ_a	Air Density (kg/m^3)
i_v	Water steam enthalpy	ρ_w	Water Density (kg/m^3)

1. INTRODUCTION

Towers are cooling systems by flow of water the temperature is reduced and the excess heat is transferred to the environment. Operation of cooling tower is airflow. In wet cooling tower, there is a direct contact between water and air and mass and heat transfer between water and air occurred by direct contact between them. In other words, the heat is released in these towers by means of convective heat transfer between water droplets and the surrounding environment. The evaporated water droplets are carried out from the system by the moving air. Therefore, in the process of cooling, heat and mass are transferred.

The duty of packing, packed cooling tower is to increase the water contact with air and water flow inside

*Corresponding Author Email: naser.kordani@umz.ac.ir (N. Kordani)

Please cite this article as: A. Asghari, N. Kordani, Effect of Ambient Condition on the Shower Cooling Tower in Four Type of Climates Condition, International Journal of Engineering (IJE),IJE TRANSACTIONS B: Applications Vol. 31, No. 5, (May 2018) 841-846

the tower. In traditional system, wood was used as the main material in construction of fillers. Although, nowadays, fillers are often made of plastic or poly vinyl chloride (PVC); however, wood is still the most accessible material. Although, cooling towers with fillers are widely used in many industries, but there are also major problems associated with old system. Among these problems, there are microorganisms that caused exacerbate corrosion and fouling in industrial units. These microorganisms generally include algae, fungi and bacteria through water or air that passes through the tower into the system. Water in the filling pores as well as the upper part of the tower is not exposed to sunlight and it is the best place for the growth of these types of microorganisms. Tao Ning and partners [1] empirically the effect of blocked nozzles the thermal performance of a cooling tower and the efficiency of cooling systems have been examined under different conditions. The results of this study showed that sediment in fillings are the most important factors that affected the thermal efficiency of these towers and their ability decreases by the amount of water temperature drop. Sungure and partners [2] by creating a prototype of biofilm with a combination of different species of sulfate-reducing bacteria (SRB), they studied the impact of its effect on the galvanized steel. It was demonstrated that under certain conditions the SRB have caused corrosion and weight losses, which is often occurred in the cooling system.

The first practical step in solving the problem of direct current was moved by Merkle [3]. So that every drop of water inside the tower, by the effect of ambient air which enters the lower end of the tower, gets cool.

To avoid the forgoing, researchers have tried to a new type of cooling tower which is called shower cooling tower (SCT). In this system, the packings are completely removable as shown in Figure 1; the environment is in direct contact and heat transfer takes place in two approaches of sensible and latent. In SCT, fillers are completely removable which are replaced by water spreader.

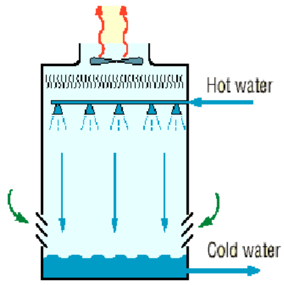

Figure 1. Schematics of SCT (Counter current)

TABLE 1. Summary of researches conducted on SCT

Investigators	Date of publication	Type of research	Studied area	Extracted findings
Givoni and Alhamidi	1995	Experimental	SCT operated in Riyadh	With the inlet air temperature 45 °C, relative humidity 50%, exhaust air temperature can be reduced up to a temperature of 29 °C [5]
Satoshi and Givoni	1997	Experimental	STC studied in Japan	Outlet temperature to the height of the tower, the tower physical conditions, environmental conditions, discharge of water depends on the type of spreader [4]
Givoni	1997	Experimental	SCT examined in three different climates	The effect on reducing the height and mass of water flow temperature in the tower are examined
Xiaoni	2006	Numerical solution	Suggested movement of water drops	According to the laws of conservation of mass and energy, SCT behavior was studied by the movement of water drops [5]
Xiaoni and Zhenvan	2007	Numerical solution	Used the concept of artificial neural network computer program	By eliminating assumptions, the accuracy of the results did not increase a lot. In some conditions the use of assumptions reduced the concentration [6]
Xiaoni	2008	Numerical solution	Numerical solving mathematical model	Logical methods between the statistical data given to heat and mass transfer (HMT) model have a high degree of accuracy. However, this model is not alternative of (HMT) because the accuracy of the output results in the method of (PPR) depends on input data [7]
Xiaoni	2013	Numerical solution	Determination of exergy and energy in SCT	Exergy during the whole tower is not absorbed by air and a substantial part of it, especially in the bottom of the tower is destroyed [8]
Muangnoi	2014	Numerical solution	Effect of operating parameters on the exergy	Changes in the initial droplet diameter, the largest water velocity impact, have the least impact [9]
Xiaoni and partner	2016	Numerical solution	Check the salt in sea water in the tower outlet temperature	Purified water or seawater will yield the same results in SCT [10]

Therefore, the water drops are placed directly in contact with air; the mass transfer and heat transfer takes place through water droplets. Water sprayed came out as droplets; that should increase the contact area between water and air, as a result, the efficiency increases and the outlet temperature decreases. Heat and mass transfer occurred from the surface of the water drops, spray water increased due to additional contact area. In fact, such increase plays an important role in the reduction of water outlet temperature. Michley [11] designed air conditioning equipment as the SCT for the first time was introduced and examined by Givoni and Alhamidi [12]. They used a system for air cooler in hot areas. Table 1 summarized a few current research conducted on SCT.

2. HEAT AND MASS TRANSFER EQUATIONS IN SCT

Water droplets sprayed from a nozzle into a spherical shape and sedentary, such as splashing, spreading far apart along the path, and eliminates the fact of not being sedentary in the flow. That the force acting on the drop includes, force of gravity, force of buoyancy and resistance of air force.

$$G_d = m g = \frac{\pi d_d^3 \rho_w g}{6} \; ; \; F_d = \frac{\pi d_d^3 \rho_a g}{6} \; ; R_d = \frac{\pi C_d \rho_a d_d^2 U^2}{8} \tag{1}$$

According to Equation (1) and using Newton's second law we define (downward direction of the force was considered positive) kinetics equation for a cooling tower with rain drops is obtained which is given the the following equation [8]:

$$\rho_w U_d \frac{dU_d}{dz} = (\rho_w - \rho_a) g - 3C_d \rho_a (u_d - u_a)^2 / 4d_d \tag{2}$$

The water flow which is in direct contact with the air has latent and sensible heat. The latent heat is due to water evaporation and sensible heat is caused by the temperature difference [7]. Latent and sensible heat is equal to:

$$dQ = dQ_c + dQ_e \tag{3}$$

$$dQ_c = h_c (T_w - T_a) dA \quad dQ_e = i_v h_d (w_{sw} - w_a) dA \tag{4}$$

$$\frac{d_{ima}}{dz} = \frac{dQ}{m_a} = \left(\frac{m_w}{m_a}\right) \frac{6h_d}{\rho_w u_d d_d} (i_{masw} - i_{ma}) \tag{5}$$

The amount of mass change in a drop equals to the amount of mass transfer from the surface of drop to air [10].

$$dm_d = h_d A_d (w_{Tw} - w_a) dA_d \tag{6}$$

The energy balance for the control volume of the SCT stated as follows:

$$dm_d = m_a dw_a$$

$$\frac{dw_a}{dz} = \left(\frac{m_w}{m_a}\right) \frac{6h_d}{\rho_w u_d d_d} (w_{Tw} - w_a) \tag{7}$$

Sensible heat caused by the temperature difference is equal to:

$$Q_{dc} = h_c A_d (T_w - T_a) \tag{8}$$

Latent heat of evaporation of water is obtained from the following equation:

$$Q_{de} = h_d A_d (w_{Tw} - w_a) i_v \tag{9}$$

$$\frac{dT_w}{dz} = \frac{-6h_d}{cp_w \rho_w u_d d_d} (i_{masw} - i_{ma}) \tag{10}$$

The change of the mass of drop during the period of time that travels the distance is equal to:

$$m_d = h_d A_d (w_{Tw} - w_a) \qquad dm_d \frac{u_d}{dz} = h_d (w_{Tw} - w_a) d_A \tag{11}$$

By incorporation of equation related to mass and cross section of drop the change of diameter can be obtained by the above equation.

$$\frac{d(d_d)}{dz} = \frac{6h_d}{\rho_w u_d} (w_{Tw} - w_a) \tag{12}$$

3. ANALYSIS OF THE RESULTS

Relative humidity for different climates differs according to the type of the weather. Relative humidity is defined by the ratio of the humidity in the air at a specific temperature compared to the amount of humidity, air could contain at the same degree of temperature. At high levels of relative humidity, latent heat transfer decreases and the mechanism of the heat transfer become sensible heat transfer. Therefore, the reduction of temperature in comparison to low relative humidity, would be lower. As a result the temperature of the outlet water increase with increasing the relative humidity. Figure 2 shows the effect of ambient air temperature on the outlet temperature of the tower according to relative humidity. With the increase of ambient air temperature, the outlet temperature from the tower increases. Because of the increase in ambient air temperature, the temperature differences (ambient air temperature and the temperature of incoming water to the tower) decreases and sensible heat transfer is reduced, as a result the outlet temperature decreases. The reduction in the temperature difference between the incoming water to the tower with the dry bubble is, the higher the temperature of water outlet from the tower . In fact the slope of the curve is reduced, and the lower the temperature of the dry bubble gets (the temperature difference between incoming water and dry bubble increases) resulted in the reduced temperature of the outlet.

The temperature of dry bubble and relative humidity of SCT is considered according to the average of the three months of summer and the hottest hours of the day (between 12 o'clock and 15) based on the recorded results received from the meteorological stations across the country[2] in the year 2013 and the journal published by the national Management and planning organization for designing the conditions of summer and winter.

For detailed review and the method of performance of SCT, the rate of temperature drop based on minimum and maximum temperature (the average of temperature of the day) for summer and winter conditions. Table 2 summarizes the average temperature of dry bubble and relative humidity for different terms of climatic areas. Table 3 shows the amount of inlets in order to calculate the temperature of outlet water from SCT and for the comparison of the four areas these amounts were considered fixed, and the ambient parameters (relative humidity and temperature of dry bubble) for each area was different. Figure 3 diagram shows the temperature drop for four climatic areas in summer conditions.

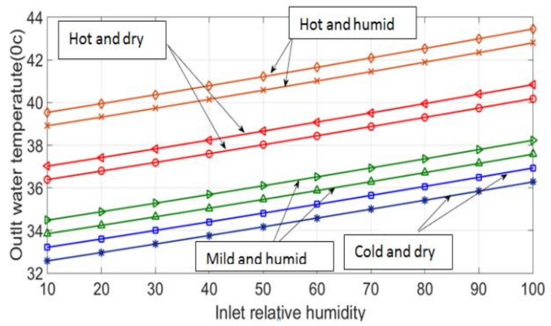

Figure 2. the effect of dry bubble temperature on the decrease of outlet temperature (tower height 10m, water to air mass ratio 1.2, droplet velocity 3.5m/s, Inlet air speed 3m/s droplet diameter 0.9mm, inlet water temperature 50°c)

TABLE 2. Average of temperature and humidity in four climatic areas

Average humidity (%)		Average temperature (°C)		Climatic area
winter	summer	Winter	summer	
65	33	-5.2	30.8	Cold and dry
46	18.5	-2	36.8	Hot and dry
79	62	13.9	41	Hot and humid
87	67	4.5	31.6	Mild and humid

[2]http://www.irimo.ir/eng/

TABLE 3. Characteristic of inlet cooling tower for different areas of Iran

Temperature of inlet water	50°C
Mass flow Ratio of water to air	1.2
Inlet air speed	3 m/s
Speed of droplet	3.5 m/s
Diameter of droplet	0.9 mm
Height of the nuzzle	10 m

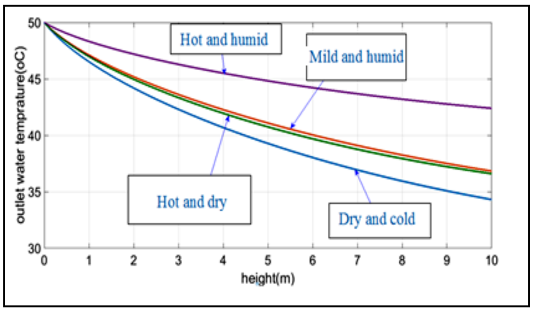

Figure 3. diagrams of droplet temperature for the four climatic areas in summer conditions

According to this chart, cold and dry areas have the highest temperature drop whereas areas hot and humid areas have the lowest temperature drop. Since ambient factors have a high effect on the reduction of the outlet temperature, in cold and dry areas, the temperature drop is high due to the low temperature of the dry bubble and in hot and humid areas have relatively high relative humidity and dry bubble; therefore, we have the least temperature drop.

The relative humidity in hot and dry areas and the dry bubble in mild and humid areas are low therefore they are in better conditions compared to hot and humid areas. In summer conditions for cold and dry areas there is an average of 17 °C drop in temperature whereas in hot and humid areas the average temperature drop is around 8°C. If the diameter of the droplet is 0.7 mm the amount of average temperature drop in cold and dry areas will be 20°C and for the hot and humid areas it would roughly be around 10°C.

The chart of Figure 4 shows the amount of drop in temperature in accordance with relative humidity. Although for hot and dry areas the temperature of dry bubble is higher compared to mild and humid areas but the average of relative humidity for these areas are considerably lower (18.5%) than mild and humid areas (more than 60%). It is worth to be mentioned that the drop in temperature due to a decrease in relative humidity is less than it was when the temperature drop caused by decrease in dry bubble temperature.

Figure 5 shows variations in temperature outlet from SCT based on the height of the nuzzle. Figure 6 shows the range of temperature drop according to relative humidity.

In which, considering the low dry bubble temperature in dry areas, we witness the highest drop in temperature and on the other hand in hot and dry areas even though the ambient temperature was high but due to the low levels of relative humidity, they are in better conditions compared to mild and humid areas; because in mild and humid areas the relative humidity is high. In hot and humid areas the temperature drop is barley sensible due to an increase in dry bubble temperature and in relative humidity.

By comparing the diagrams we understand that the amount of temperature drop in hot and dry areas in comparison with the mild and humid areas, is higher in winter conditions than it is in summer conditions.

Because in hot and dry areas the temperature of dry bubble in winter conditions is lower than the temperature in mild and humid areas, on the other hand the relative humidity of mild and humid areas is far more higher than in hot and dry areas.

Figure 7 depicts the temperature drop for the four areas on summer, winter and annual terms, in that, the cold and dry areas had the highest temperature drop while the hot and humid had the lowest. Considering the high temperature difference in the two seasons of summer and winter for hot and dry areas and hot and humid areas the diagram for these two areas in winter had a higher degree of slope.

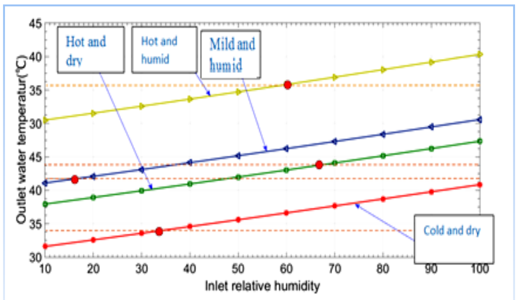

Figure 4. droplet temperature according to relative humidity for the four areas in summer conditions

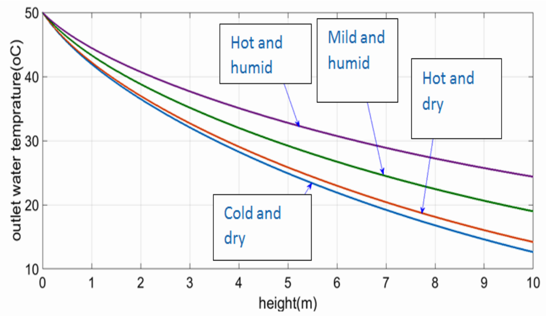

Figure 5. diagrams of droplet temperature for the four climatic areas in winter conditions

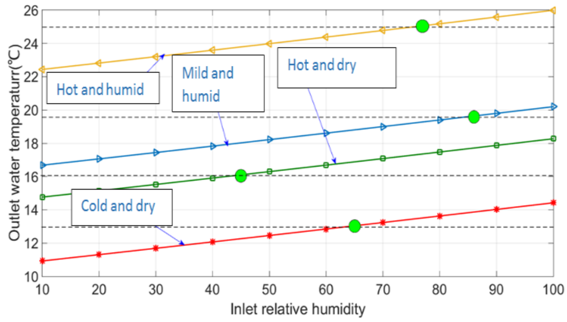

Figure 6. temperature droplet according to relative humidity for the four climatic areas in winter conditions

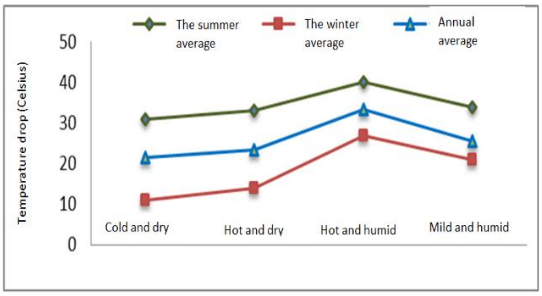

Figure 7. diagrams of droplet temperature for the four climatic areas

4. CONCLUSION

Relative humidity and the temperature of dry bubble are important factors that affect the temperature outlet of SCT and cause it to decrease. In cold and dry areas due to the low levels of ambient temperature, the amount of temperature drop is considerably high and SCT has desirable efficiency. Hot and dry areas had low levels of relative humidity and this causes the latent heat transfer to decrease and as a result the amount of drop in temperature in the area decreases.

Sprayed water in forms of small droplets that exchange their heat energy with the cold air, expand the water-air contact surface. With the increase in mass transfer, problems caused by sediment disease microorganisms comes to a minimum.

In high levels of relative humidity, the latent heat transfer decreases and the heat transfer mechanism, would be the sensible heat transfer.

If the temperature difference between the dry bubble and inlet water is low, the drop in temperature will also be low, which is lower in high levels of relative humidity.

In accordance to the effect the environmental factors on the reduction of outlet temperature, in cold and dry climates we have the highest drop in temperature and in hot and humid climates we have the least temperature drop.

The temperature difference of the outlet of the tower between the two seasons of summer and winter in cold and dry areas was greater than the other areas due to high temperature difference of dry bubble in summer and in winter.

5. REFERENCES

1. Ning, T., Chong, D., Jia, M., Wang, J. and Yan, J., "Experimental investigation on the performance of wet cooling towers with defects in power plants", ***Applied Thermal Engineering***, Vol. 78, (2015), 228-235.
2. Ilhan-Sungur, E. and Çotuk, A., "Microbial corrosion of galvanized steel in a simulated recirculating cooling tower system", ***Corrosion Science***, Vol. 52, No. 1, (2010), 161-171.
3. Merkel, F., "Verdunstungskfjhlung", ***VDI Forschungsarbeiten***, No. 275.
4. Yajima, S. and Givoni, B., "Experimental performance of the shower cooling tower in japan", ***Renewable Energy***, Vol. 10, No. 2-3, (1997), 179-183.
5. Givoni, B., "Performance of the "shower" cooling tower in different climates", ***Renewable Energy***, Vol. 10, No. 2-3, (1997), 173-178.
6. Qi, X., Liu, Z. and Li, D., "Performance characteristics of a shower cooling tower", ***Energy conversion and management***, Vol. 48, No. 1, (2007), 193-203.
7. Qi, X., Liu, Z. and Li, D., "Numerical simulation of shower cooling tower based on artificial neural network", ***Energy Conversion and Management***, Vol. 49, No. 4, (2008), 724-732.
8. Qi, X., Liu, Z. and Li, D., "Prediction of the performance of a shower cooling tower based on projection pursuit regression", ***Applied Thermal Engineering***, Vol. 28, No. 8-9, (2008), 1031-1038.
9. Muangnoi, T., Asvapoositkul, W. and Hungspreugs, P., "Performance characteristics of a downward spray water-jet cooling tower", ***Applied Thermal Engineering***, Vol. 69, No. 1-2, (2014), 165-176.
10. Qi, X., Liu, Y., Guo, Q., Yu, J. and Yu, S., "Performance prediction of seawater shower cooling towers", ***Energy***, Vol. 97, (2016), 435-443.
11. Mickley, H.S., "Design of forced draft air conditioning equipment", ***Chemical Engineering Progress***, Vol. 45, No. 12, (1949), 739-745.
12. Givoni, B. and Al-Hemiddi, N., *Applicability of a``shower``passive cooling tower in a hot dry climate*. 1995, American Solar Energy Society, Boulder, CO (United States).

Effect of Ambient Condition on the Shower Cooling Tower in Four Type of Climates Condition

A. Asghari[a], N. Kordani[b]

[a]Faculty of Mechanical Engineering, Islamic Azad University, Noor Branch
[b]Faculty of Mechanical Engineering, University of Mazandaran, Babolsar, Iran

PAPER INFO

Paper history:
Received 13March 2017
Received in revised form 13January 2018
Accepted 14February 2018

Keywords:
Shower Cooling Tower
Heat Transfer
Mass Transfer

چکیده

عمل سرمایش آب توسط هوای محیط بادومکانیزم انتقال حرارت وجرم صورت می‌گیرد. وظیفه برج‌های خنک‌کن، جذب گرما از یک فرایند ودفع آن به فضایا اتمسفر است. استفاده از پکینگ ها در برج های خنک کننده تر دارای معایبی ازجمله انسداد مسیر، کاهش طول عمر و تولید جلبک ها و قارچ می باشد. نوع جدیدی از برج ها که به برج خنک کننده بارشی معرف است در آن پکینگ ها بطور کامل حذف و آب در تماس مستقیم هوای ورودی قرارگرفته و انتقال حرارت به دو صورت نهان و محسوس انجام می‌پذیرد. در این مقاله مدل سازی ریاضی و شبیه سازی برج‌ها با استفاده معادلات دیفرانسل حاکم انجام گرفته است. معادلات دیفرانسیل با استفاده قوانین بقای جرم و انرژی بدست آمده و با یک برنامه کامپیوتری به حل عددی پرداخته و عملکرد برج خنک کننده بارشی در شرایط مختلف محیطی بررسی شده است. این برجها در ناحیه سرد و خشک و گرم و خشک دارای راندمان بالایی می‌باشد. در نواحی بسیار گرم با کاهش قطر قطره می توان دمای خروجی از برج را بهبود بخشید.

doi: *10.5829/ije.2018.31.05b.21*