JJMIE

Volume 16, Number 3, June. 2022
ISSN 1995-6665
Pages 421 – 428

Jordan Journal of Mechanical and Industrial Engineering

Effect of Physical Parameters on the Outlet Temperature of the Shower Cooling Tower

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Received 6 Feb 2022 Accepted 4 Apr 2022

Abstract

In the most industrial process and air conditioning systems, huge amount of heat are generated for better performance. The shower cooling tower (SCT) is used for heat transfer to the environment. In this study, mathematical modeling and tower behavior simulate based on the laws of heat and mass transfer. This is done after reviewing papers and rewriting governing differential equations using a computer program to solve numerical solution and then analyzing tower behavior. Also, the effect of physical parameters (the velocity of water droplet, inlet air velocity and water to air mass flow ratio) on reducing the outlet temperature of the water has been checked and compared with the results of the experiment, which has a great accuracy. Simulated data shows that, as the inlet air velocity increases, the corresponding heat and mass transfer coefficients increase, outlet temperature from tower decreases. Also due to the excessive increase in the droplet velocity, it does not have much effect on reducing the temperature of the outlet. By increasing the water to air mass flow ratio, decreasing of temperature is reduced.

Keywords: Shower Cooling Tower, physical parameters, Heat transfer, Mass transfer.

1. Introduction

Free cooling techniques can be used to substantially reduce energy costs. During cold weather, the outside ambient temperature can help in saving energy in refrigeration systems (Al-Salaymeh and Abdelkader (2011)). Numerical simulation of time-dependent 2-dimensional forced convection flow over a pair of tandem circular cylinders in a rectangular channel has been carried out by Oyewola et al. (2019). This work suggests that in minimizing the vibration of the tubes and enhancing effective heat transfer by the heat exchangers, the aforementioned parameters and conditions should be taken into consideration.

Choosing the right cooling towers, requires complete recognition of the relevant parameters that will improve the thermal efficiency of the system. By knowing the exact performance of the tower in different conditions, investigating and providing operational conditions and optimal design, the cooling tower can save on water consumption, energy and maintenance costs. Investigating of SCT thermal performance is highly important. With rectification of the heat and mass transfer coefficients, and change in tower height, especially droplet diameter of the dots, one can increase the accuracy of the calculations relative to the other towers. The outlet temperature of water depends on the environmental conditions. By increasing environment temperature, the output temperature from the tower also increases. Therefore, changing the physical and geometric conditions can improve the outlet temperature of the tower.

At the beginnings of 19th century, lots of theories were devised to justify the transfer of heat and mass in evaporating water facility devices that have been invented, which are based on basic engineering rule. Cooling tower can be considered as a heat exchanger which water and air are in direct contact together. But no theoretical or experimental relation can precisely compute the total contact surface in a tower, to define a specific heat transfer coefficient for it. This problem becomes more complicated despite the phenomenon of mass transfer. Therefore, the design of the tower relies on a relationship that is confirmed by experiments and real examples. These relationships can be used to design or predict the tower's performance, if the design conditions change.

Over the past century, many researchers have studied the performance of cooling towers. The first practical step in solving the problem of direct current tower was taken by Merkel (1925). Merkel method was a combination of differential equations of mass transfer and air/water heat inside a tower.

A method was proposed by Suthedand (1997) in which an exact solution was used to solve the equations governing the cooling tower. Suthedand, in his model, considered the whole tower as a control volume, and

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adjusted its differential equations based on quantity changes from above to the bottom of the tower. In his model, he considered the effects of evapotranspiration of input water and assumed the factorial in the opposite tower. He solved the differential equations for his exact solution with the Tower A Program and the equations for the approximate computer solution, which was the same as the Merkel method with the program of Tower B solution was solved by Runge-Kutta (4th order) method. He also showed that neglecting the evaporation of water for the typical operating conditions of a sample in a tower could lead to further errors in higher ratios of water to air mass flow rates. For example, for water to air mass flow ratio equal to 2, it is 14%.

Wang and Nianping (2011) calculate mathematical equations of this type of Tower using of thermodynamic relations and examined the effect of various parameters on the thermal performance of these towers.

Asvapoositkul and Treeutok (2012) also investigated these towers operational in variable climate condition and obtain an accurate and simple equation compare to others.

SCT was first introduced and investigated by Givoni (1995). This tower consisted of a body (shell) with nozzles at the top and tank for collecting water at the end. In this tower, water from above was turned into fine droplets by spray nozzles, and along the path to the bottom of the tower. The Cooled air was also released from the top of the tower, Givoni and Al Hemiddi examined this tower in Riyadh, Saudi Arabia. with a maximum inlet air temperature 45 °c and relative humidity 50%, a drop in temperature of 16 °c. Satoshi and Givoni (1997) studied the thermal performance of SCT in japan. They measured inlet and outlet condition of air with respect to change in water flow in different time of the day in various heights. They showed that outlet air temperature depends on tower height, ambient condition, water flow, and distributer's types. He also investigated height and water flow effect on air temperature reduction of tower's used as air conditioner, and indicates that temperature reduces extremely in height less than 0.5 m. But with increase in height, outlet temperature reduction will decrease. Experimental investigations have been done to understanding these towers, but also they may not present a practical theory to study the system and predict result in mathematical equation [8]. Although by that time, no numerical analysis for the study of these systems was available, Xiaoni and his coworkers (2007) suggested one dimensional model, heat and mass Transfer (HMT) with experimental data and rules based on heat and mass conservation, to study water droplet displacement, so they study tower behavior.

Muangnoi and coworkers (2014) studied physical and geometrical parameter on the SCT and stated that the change in initial droplet diameter was the most, and that water velocity had the least effect.

In SCT (opposite current), sprayed water droplets exchange their thermal energy with cold water, so with increase area, heat exchange between the water droplets and air will increase, and increasing the height and exchange time as a result, the output temperature decreases.

Zunaid (2018a, b) investigated the effect of variation in air relative humidity and inlet water to air mass flow ratio on outlet temperature of SCT. The thermal efficiency of SCT increases with increasing the inlet air relative humidity and decreases with increasing the water to air mass flow ratio.

Anbazhaghan and his coworkers (2021) presented a two-dimensional model of water droplet collision to reduce errors in Xiaoni models.

Previous research conducted on the performance of a shower cooling tower has not considered the effect of physical parameters. So it is possible to improve outlet temperature and operation time with appropriate design (the velocity of water droplet, inlet air velocity and water to air mass flow ratio) depending on ambient condition.

2. Mathematical model and Governing Equations on SCT

Assumptions:

1. The Lewis factor is equal to one
2. Physical properties of the water are the same in hot and cold temperature
3. The water droplet moving in the tower act in the shapes of ball
4. The whole motion direction of the water droplet is vertical. It is assumed that the water droplet rises or falls vertically in one dimension.
5. The radiation heat transfer is ignored because of the small temperature difference.

For better checking of shower cooling tower performance, it is best to first study of heat and mass transfer at the surface of the drop of water. Movement acceleration, turbulence value, internal circulation and evaporation of water droplets have important effects on the performance of SCT.

2.1. Droplet velocity analysis during SCT

The droplets of water sprayed from the nozzle in a spherical and even form, eliminate droplet collisions, dispersal along the path, and non-uniformity of the flow. For a better understanding, consider a drop of water as shown in Figures 1 and 2.

The forces that enter the drop are: gravity, floating force, and air resistance

$$G_d = m_d g = \frac{\pi d_d^3 \rho_w g}{6} \tag{1}$$

$$F_d = \frac{\pi d_d^3 \rho_a g}{6} \tag{2}$$

$$R_d = \frac{\pi C_d \rho_a d_d^2 U^2}{8} \tag{3}$$

In equations 1-3, C_d (drag coefficient) is equal to:

For laminar flow

$$C_d = 18.5 / \mathrm{Re}^{3/5}$$

$$0.9169 \le \mathrm{Re} < 508.3917$$

For turbulence flow

$$C_d = 0.44$$

$$\mathrm{Re} \ge 508.3917$$

It was used Newton's second law definition (for the direction of power to be considered as positive):

$$a_d = \frac{\sum F}{m_w} = \frac{G_d - F_d - R_d}{m_w}$$

$$U_d = dz/dt \; ; \; a_d = \frac{du_d}{dt} = u_d \frac{du_d}{dz} \tag{4}$$

The equations given can be combined to obtain the kinetic equation for water droplets in the SCT:

$$\rho_w u_d \frac{du_d}{dz} = (\rho_w - \rho_a) g - 3C_d \rho_a (u_d - u_a)^2 / 4d_d \tag{5}$$

2.2. Analyses of enthalpy changes, temperature and humidity during SCT

The internal energy of a drop in the system changes with the loss of the amount of latent and tangible heat. For this purpose, that was considered a tower of height H and divide it into N equal to the thickness of dz. For a better understanding, a volumetric element was considered considering mass and heat transfer (Figure 2).

Total heat transfer at the common climate level, including heat transfer due to evaporation and transfer of heat.

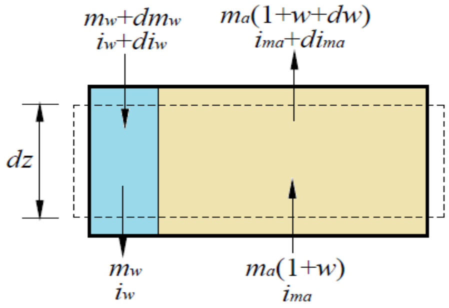

Figure 1. Volume control SCT (Xiaoni et. al (2008c))

Mass balance for the control volume is equal to:

$$dm_w = m_a dw \tag{6}$$

Energy balance for the control volume is equal to:

$$m_a di_{ma} = m_w di_w + i_w dm_w \tag{7}$$

In the above equation i_w is air enthalpy and i_{ma} is a enthalpy of the mixture of water and air.

The water flow that is directly in contact with the air involves a transient and tangible heat loss. The latent transmission is due to the evaporation of water and the transmission of tangential effects due to temperature differences.

$$dQ = dQ_c + dQ_e \tag{8}$$

The hidden and sensitive heat is equal to:

$$dQ_c = h_c (T_w - T_a) dA$$

$$dQ_e = i_v h_d (w_{sw} - w_a) dA \tag{9}$$

The temperature difference in the equation can be replaced by enthalpy variations. The enthalpy of the saturated air at the local temperature is shown below:

$$i_{masw} = c_{pa} T_w + w i_v + (w_{sw} - w) i_v \tag{10}$$

The enthalpy of vapor mixtures for dry air units can be calculated as follows:

$$i_{ma} = c_{pa} T_a + w (i_{fgw0} + c_{pv} T_a) \tag{11}$$

$$T_w - T_a = \frac{(i_{masw} - i_{ma}) - (w_{sw} - w) i_v}{c_{pma}} \tag{12}$$

$$dQ = h_d \left[\frac{h_c}{h_d c_{pma}} (i_{masw} - i_{ma}) + \left(1 - \frac{h_c}{h_d c_{pma}}\right) i_v (w_{sw} - w) \right] dA \tag{13}$$

With factorization from h_d and Louis factor equal to one we have:

With replacing upon equations for enthalpy differences:

$$\frac{d_{ima}}{dz} = \frac{dQ}{m_a} = \left(\frac{m_w}{m_a}\right) \frac{6h_d}{\rho_w u_d d_d} (i_{masw} - i_{ma}) \tag{14}$$

The mass change of a drop is equal to the amount of mass transfer from the droplet to the air.

$$dm_d = h_d A_d (w_{Tw} - w_a) dA_d \tag{15}$$

By setting the mass of the droplet according to (1) and the area of the sphere $(A_d = \pi d_d^2)$ in the equation 15, the equation of moisture change is obtained which is equal to.

$$\frac{dw_a}{dz} = \left(\frac{m_w}{m_a}\right) \frac{6h_d}{\rho_w u_d d_d} (w_{Tw} - w_a) \tag{16}$$

h_d is mass transfer coefficient in equation 16.

$$h_d = h_c / (cp_a + w_a cp_\upsilon) \tag{17}$$

$$h_c = \frac{k_a \times Nu_d}{d_d}$$

Internal energy differences is equal to summation of sensible heat due to temperature difference and latent heat due to water evaporation.

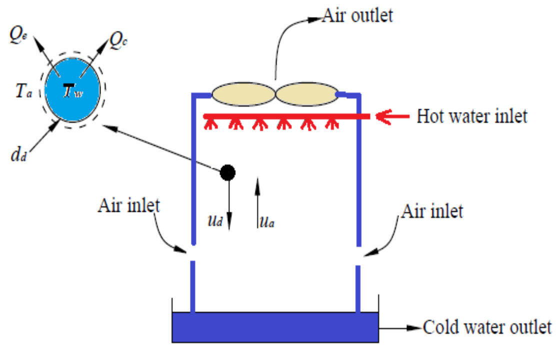

Figure 2. Energy transfer in droplet surface (Xiaoni et. al (2008c))

Sensible heat is equivalent to:

$$\frac{dU_d}{dt} = -(Q_{dc} + Q_{de}) \tag{18}$$

$$Q_{dc} = h_c A_d (T_w - T_a) \tag{19}$$

Latent heat is obtainable from following equation:

$$Q_{de} = h_d A_d (w_{Tw} - w_a) i_\upsilon \tag{20}$$

Internal energy is equal to:

$$dU_d = -\left[h_c A_d (T_w - T_a) + h_d A_d (w_{Tw} - w_a) i_\upsilon \right] \tag{21}$$

$$m_d c_{pw} dT_w = -A_d h_d \left[\frac{h_c}{h_d} (T_w - T_a) + i_\upsilon (w_{sw} - w_a) \right] \tag{22}$$

$$m_d c_{pw} dT_w = -A_d h_d (i_{masw} - i_{ma}) \tag{23}$$

Temperature difference equation is obtainable with replacing mass and droplet area:

$$\frac{dT_w}{dz} = \frac{-6h_d}{cp_w \rho_w u_d d_d} (i_{masw} - i_{ma}) \tag{24}$$

2.3. Droplet diameter changes in the SCT

Droplet mass variations in dz is:

$$m_d = h_d A_d \left(w_{Tw} - w_a\right)$$

$$dm_d \frac{u_d}{dz} = h_d \left(w_{Tw} - w_a\right) d_A \tag{25}$$

With replacing mass equations and droplet cross section area in equation, change of droplet diameter has been obtained.

$$\frac{d\left(d_d\right)}{dz} = \frac{6h_d}{\rho_w u_d}\left(w_{Tw} - w_a\right) \tag{26}$$

3. Analysis of the results

Physical parameters (drop velocity, inlet air velocity, and flow ratio) are investigated with changes in environmental conditions and assuming that the geometric parameters (droplet diameter and nozzle height) are constant, because the environmental parameters are different for different climates.

Table 1. Ambient and geometrical parameter range in SCT

Nozzle height (m)	10
Droplet diameter (mm)	0.8
Dry bulb temperature (°C)	25-35
Relative humidity (%)	20-80
Water inlet temperature (°C)	50

3.1. Droplet initial velocity investigation in SCT

The analysis of the graphs in Figures 3 and 4 shows that the effect of the initial velocity of droplet spray on the decrease in the outlet temperature is not significant, as it is obvious that the droplet reaches its limit velocity after a period of time and then moves at a constant velocity. So that the droplet velocity is high at the beginning of the nozzle and is constant from a height of 3 meter to the end, which is approximately the same for the different relative humilities.

Increasing the droplet velocity causes the droplet to reach the end of the tower faster. In this case, there is not enough time to exchange heat (water to air), or in other words, the droplet does not have enough time to transfer heat during the time of movement (first to the end of the tower). On the other hand, slowing down will cause a large amount of water droplets to drop out of the tower due to air velocity, which will increase the evaporation rate.

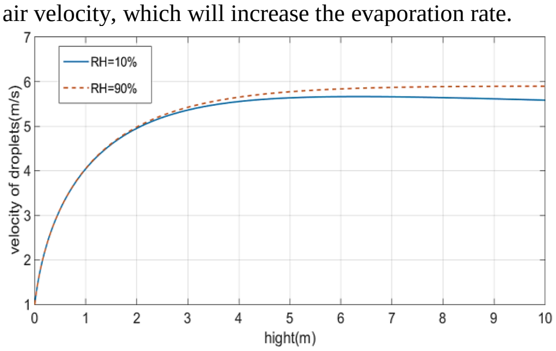

Figure 3. The droplet velocity related to height diagram with initial velocity 1m/s (tower height 10 m, water to air mass flow ratio 1.2, inlet air velocity 2 m/s, droplet diameter 0.8mm, inlet water temperature 50 °C and dry bulb temperature is 25 °C).

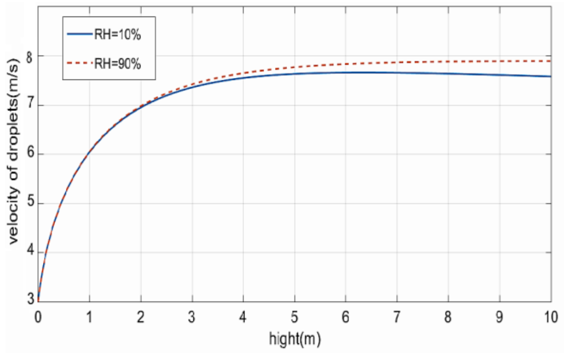

Figure 4. Droplet velocity-height diagram with initial velocity 3 m/s (nozzle height 10 m, water to air mass flow ratio 1.2, inlet air velocity 2m/s, droplet diameter 0.8 mm, inlet water temperature 50 °C and dry bulb temperature is 25 °C)

By comparing these diagrams, it is evident that with increasing initial velocity of the droplet, the temperature of the outlet of the water increases. As the input velocity increases, the durability time decreases and droplet exchange rate decreases along the tower. In this case, the output temperature is increased according to the diagram. Of course, the temperature increase is negligible. On the other hand, due to the increased durability of the droplet along the tower, the rate of evaporation increases. The values of water temperature output at various velocities are given in Table 2.

Table 2. Droplet velocity effect on outlet water temperature (°C)

Droplet initial velocity (m/s) / Relative humidity (%)	1	2	3	4	5
25%	33.3	33.5	33.7	33.9	34.2
%50	34.3	34.5	34.7	34.9	35.3
80%	35.6	35.8	36	36.1	36.4

3.2. Effect of air velocity in SCT

As the air velocity increases, the temperature of the air outlet from the tower decreases. Heat and mass transfer coefficients are directly related to the Reynolds number. Therefore, increasing the inlet air velocity, the coefficients of mass transfer and heat increase. Then the heat exchange rate increases and causes a decrease of the outlet temperature of the tower. In higher velocities, temperature drop rate is increasing.

By increasing the temperature of the dry bulb, the difference in temperature decreases (the temperature difference between the dry bulb and the inlet water). In this case, the tangible heat transfer is reduced, but the temperature difference between the dry bulb and the wet bulb is increased. As the relative humidity increases, in addition to the tangible heat transfer, the latent heat transfer is also increased. Therefore, the increase in the air flow rate will lose its effect on reducing the output temperature. As a result, by increasing of relative humidity, reducing the temperature of the outlet water from the SCT is less. In fact, the graphs of figure 6 have a greater slope than figure 5. If the temperature of the dry bulb increases, so that the temperature of the dry bulb is equal to the inlet water temperature (50 °C), then the temperature drop rate in relative humidity above 95% is approximately zero.

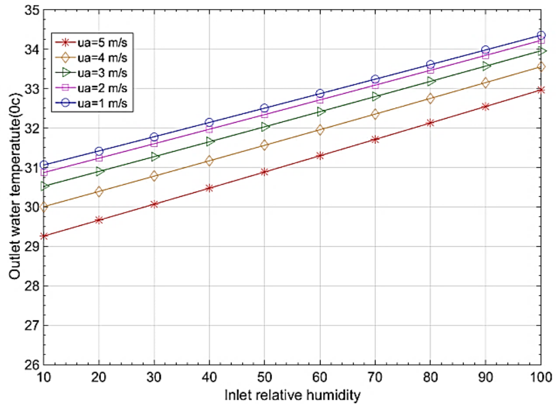

Figure 5. Effect of air velocity on outlet water temperature with dry bulb temperature 25 °C (nozzle height 10 m, water to air mass ratio 1.2, droplet velocity 2m/s, droplet diameter 0.8mm, inlet water temperature 50 °C)

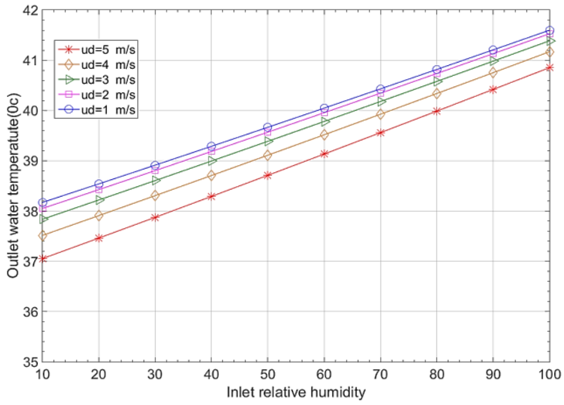

Figure 6. Effect of air velocity on outlet water temperature with dry bulb temperature 35 °C (nozzle height 10 m, water to air mass ratio 1.2, droplet velocity 2 m/s, droplet diameter 0.8mm, inlet water temperature 50 °C)

Figure 8 shows that with increase of the inlet air temperature, reduction in tower outlet temperature is more. In fact, the decreasing rate of outlet temperature is more, when the inlet air velocity is increased from 4 to 5 m/s in compare with increasing of inlet air velocity from 1 to 2 m/s due to the square power of the velocity in the Reynolds number.

Considering that increasing of inlet air velocity causes decreasing of the outlet water temperature, but increasing of velocity increase evaporation rate.

Tables 3 and 4 shows decreasing rate of outlet temperature from the SCT in different droplet diameter and height. As nozzle height increase, the temperature reduction rate is increased. By increasing of droplet diameter, the temperature reduction rate is decreased. Also shows that by increasing of inlet air velocities, the temperature reduction rate is increased. This is more at the higher velocities. The temperature difference is negligible for lower velocities.

3.3. The effect of mass flow ratio in SCT

As it is known, with the increase of the mass flow ratio, the temperature drop decreased. (The outlet water temperature of the SCT increases). The greater proportion of flow ratio causes decreasing of temperature drops. The role of air exchange between the droplets and the environment. So by increasing of flow ratio, the amount of water ratio increases, or the air ratio decreases. As a result, more droplets spray from nozzles. Therefore, the amount of air exchange with droplets decreases, so outlet temperatures will be increased more. By increasing of the relative humidity, the temperature reduction rate is decreased, or in the other word the temperature of the outlet water from the tower increases.

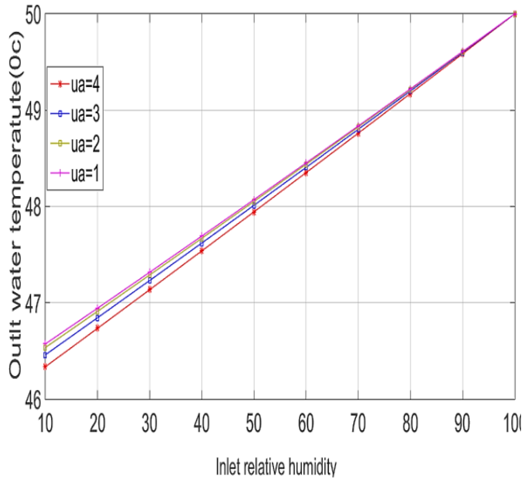

Figure 7. Effect of air velocity on outlet water temperature with dry bulb temperature 50 °C (tower height 10 m, water to air mass flow ratio 1.2, droplet velocity 2 m/s, droplet diameter 0.8 mm, inlet water temperature 50 °C).

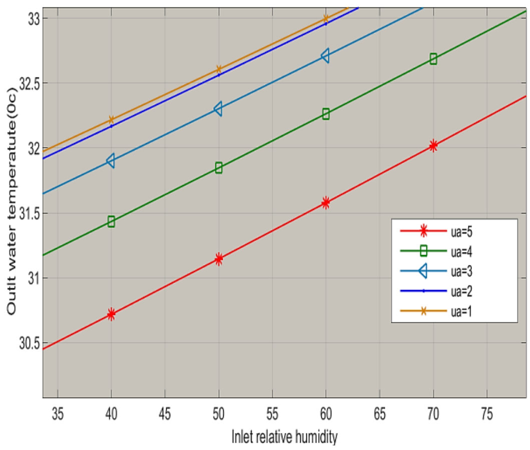

Figure 8. The effect of air velocity on the outlet water temperature with dry bulb temperature 25 °C

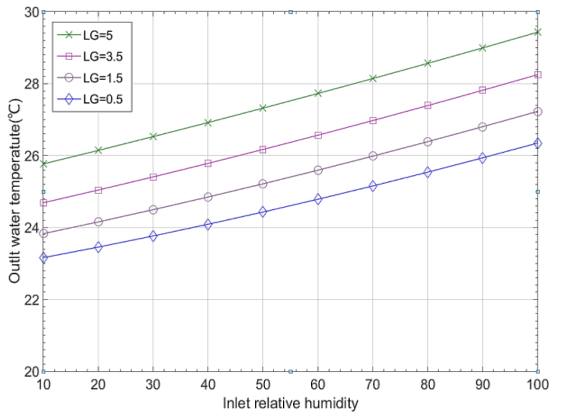

Figure 9. Effect of water to air mass flow ratio in the outlet temperature from the tower according to relative humidity (tower height 10 m, water to air mass flow ratio 1.2, droplet velocity 2 m/s, droplet diameter 0.8 mm, inlet water temperature 50 °C)

As shown in figure 9, with raise in mass flow ratio from 0.5 to 1.5, outlet temperature reduction is less than 0.6 °C and for mass flow ratio from 3.5 to 5 outlet temperature reduction is 1.2 °C. As a result, it's clear that in flow ratio more than 1.5, temperature reduction is more.

3.4. Comparison between numerical and experimental results:

Xiaoni and colleagues (2008a, b) have tried to study new methods that are capable of quick and easy estimation of the outlet temperature and are more accurate than the previous model. Therefore, attempts are made to assist the statistical relationships of the logical connection between the input and output variables (output water temperature) so that, with experimental data, we can estimate the temperature of the output water. This method is called Projection Pursui Regression (PPR), which is very good accurate in comparison with the proposed model based on Heat and Mass Transfer (HMT) equations. However, this model is not an alternative model with HMT, because the accuracy of the output results in the PPR methods are related to the input data. The results of this study have been compared to 5 other samples that has been done by Xiaoni et. al (2008c), and the results are shown in Table 5 and Figure 10.

According to Table 5, the results obtained from this study are very close to experimental results and have a better accuracy than the numerical HMT method that has been done by Xiaoni et. al (2008c). With a slight change in inputs (changes in physical conditions), the accuracy of the results can be improved. As shown in Table 5 and Figures 10, it is clear that the results of this study, with the change in physical conditions than the PPR, are also more accurate, which can improve the results by decreasing of droplet velocity.

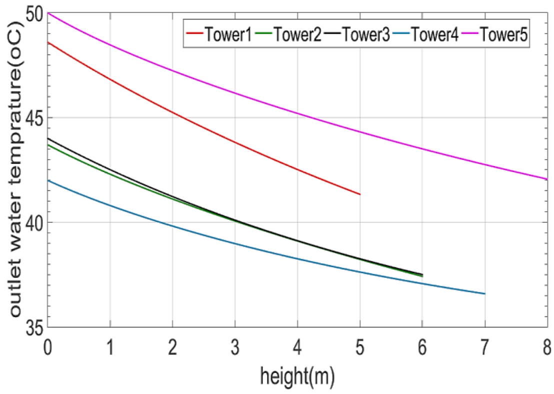

Figure 10. Outlet temperature diagrams from SCT according to height

Table 3. Outlet temperature from SCT for cold and dry climate (water to air mass flow ratio 1.2, droplet velocity 2 m/s, inlet water temperature 50 °C)

Means of $T_{a(dry)}$ °C	Means of Relative Humidity (%)	Air velocity (m/s)	H=8(m)			H=10(m)		
			d(mm)			d(mm)		
			0.7	0.8	1	0.7	0.8	1
			$T_{w(out)}$ °C					
35	38	1	35.5	36.8	39.4	34.5	35.6	38.1
		2	36	37.3	39.9	35	36.1	38.7
		3	36.3	37.7	40.1	35.3	36.4	39
		4	36.5	37.8	40.2	35.5	36.6	39.2
		5	36.5	37.8	40.2	35.6	36.7	39.3

Table 4. Outlet temperature from SCT for warm and dry district (water to air mass flow ratio 1.2, droplet velocity 2 m/s, inlet water temperature 50 °C)

Means of $T_{a(dry)}$ °C	Means of Relative Humidity (%)	Air Velocity (m/s)	H=8(m)			H=10(m)		
			d(mm)			d(mm)		
			0.7	0.8	1	0.7	0.8	1
			$T_{w(out)}$ °C					
29	63	1	31.7	33.4	37.1	30.4	32	35.4
		2	32.4	34	37.7	31	32.6	35.9
		3	32.8	34.4	37.9	31.4	33	36.2
		4	33.1	34.6	38	31.6	33.3	36.4
		5	33.1	34.6	38	31.7	33.4	36.5

Table 5. Comparison between numerical and experimental results of references and this research

	SCT 1	SCT 2	SCT 3	SCT 4	SCT 5
Nozzle height (m)	5	6	6	7	8
Droplet diameter (mm)	1	1.1	0.8	0.8	1.1
Droplet initial velocity (m/s)	2	2.4	2.5	2.3	2
Inlet air velocity (m/s)	6	5	6	5	4
Air to water ratio	0.8	1	0.9	0.9	0.8
Relative humidity (%)	69	74	70	68	78
Dry bulb temperature (°C)	48.6	43.7	44	42	69
Testing results (°C)	40.2	37.3	37.8	36.2	43.7
Result with HMT method (°C)	40.9	37.7	38.1	36.7	44.3
Result with PPR method (°C)	39.8	36.9	38	36.3	43.3
This research result (°C)	41	37.2	37.5	36.5	42.1

Table 6. Results of this research by change of droplet and inlet air velocity (other parameters according to table 5)

		SCT 1	SCT 2	SCT 3	SCT 4	SCT 5
Physical parameter as table 5	Droplet initial velocity (m/s)	2.2	2.4	2.5	2.3	2
	Inlet air velocity (m/s)	6	5	6	5	4
New physical parameter	Droplet initial velocity (m/s)	3.5	3	3.3	3	3.9
	Inlet air velocity (m/s)	3.7	2.8	3.7	2.7	2.9
This research results (°C)		40.9	3.9	3.7	36.2	41.7

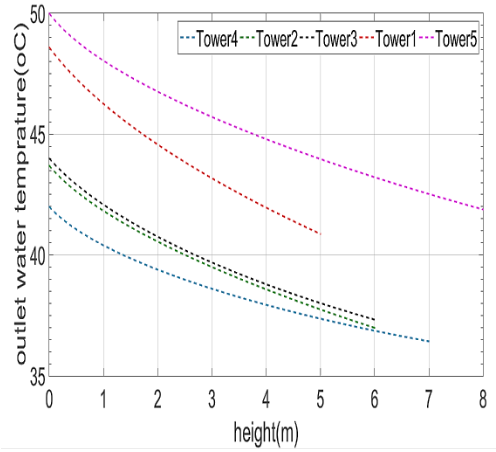

Figure 11. Outlet temperature diagrams from SCT according to height by applying changes in physical condition (table 6)

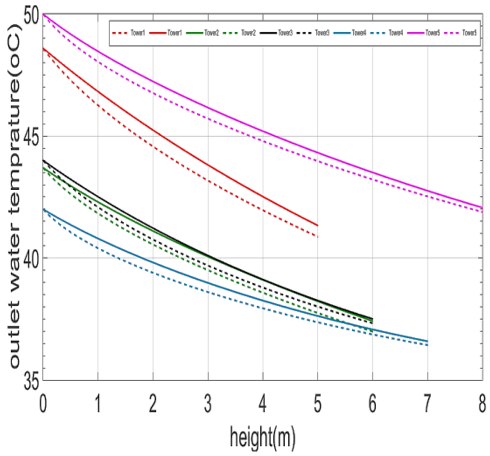

Figure 12. Outlet temperature diagrams from SCT according to height based on table 5 and by applying changes in physical condition

4. Conclusion

In this paper, mathematical models and computer program have been applied for physical parameter using HMT process. After analyzing and reviewing the results of the references, the findings of this research have been compared with the PPR statistical method that has fine precision. We find that the results can be improved by changing the physical conditions, because the high velocity of the droplet causes decreasing in droplet life time in the tower. In this case there is not enough time for heat transfer (water to air) or in other words, the droplet does not have enough opportunity to transmit heat during the movement time (first to the end of the tower), and the rise of the inlet air velocity causes an increase of evaporation rate. The overall conclusion is as follows:

1. Heat exchange from water evaporation increases with rising of flow ratio and causes increase of temperature reduction rate. By increasing of flow ratio (water flow increase or air flow decreases), temperature reduction rate increases.
2. With increasing of inlet air velocity, which corresponds to those heat and mass transfer coefficient increased, the output temperature of the tower decreases.
3. Whatever the velocity of the inlet air increases, the outlet temperature from the tower decreases.
4. In high relative humidity the latent heat transfer will reduce, and heat transfer mechanism will be tangible heat transfer. So the temperature drop will be less in comparison with lower relative humidity. As a result, with increasing of the relative humidity, the outlet water temperature increases.
5. With decreasing droplet velocity, the temperature reduction rate increases because the durability in the tower increases.
6. Droplet velocity is high at the beginning of the nozzle and is constant from heights of 3 m, which is the same for the different relative humidities.

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