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Exergy based performance analysis of a shower cooling tower

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The present study provides a descriptive mathematical model for energy and exergy for a shower cooling tower(SCT). The model is used to predict the variation of temperature and exergy along the tower length. The validity of the model for predicting variations in gas and liquid characteristics along the tower length was examined against some operating data measured in a cooling tower company. The results show that the exergy of water gets less along the height of tower. It is indicated the distribution of the exergy loss is high at the bottom and gradually low at the top of the tower. Moreover, it shows that 1.50m/s air velocity is resulted in less exergy destruction. With a decrease in the size of the water droplet, the fluids carrying energy have more opportunities for mass and energy transfers.

Keywords: shower cooling tower, exergy, heat and mass transfer

NOMENCLATURE

A area [m^2]
c specific heat [kJ/(kg·℃)]
C_d drag coefficient on droplet [dimensionless]
D_c diffusion coefficient [m^2/s]
F_d buoyancy [N]
g gravitational acceleration [m/s^2]
G_d gravity [N]
d equivalent diameter [m]
ex specific exergy [kJ/kg]
h_c heat transfer coefficient[W/m^2·℃]
h_d mass transfer coefficient [kg/m^2·s]
i_{fgw0} specific latent heat of water at 0℃ [kJ/kg]
i_{masw} specific enthalpy of saturated air evalutated at the local bulk water temperature [kJ/kg]
i_v specific vaporization heat of water [kJ/kg]
m mass [kg]
i specific enthalpy [kJ/kg]
Le_f Lewis factor
Nu Nusselt number
Pr Prantdl number
Q heat transfer rate [W]
R_d drag [N]
Re Reynold number
Sc Schmidt number
Sh Sherwood number
t time [s]
T temperature [℃]
u velocity [m/s]
U internal energy [J]
w humidity ratio of moist air evaluated at T_a [kg/kg]
z vertical coordinate [m]

GREEK LETTERS

λ thermal conductivity coefficient [W/m·K]
μ dynamic viscosity coefficient [Pa/s]
ρ density [kg/m^3]

SUBSCRIPTS

a air
c convection
d droplet
e evaporation
s saturated
v vapor
w water
1 inlet
2 outlet

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0 INTRODUCTION

Cooling towers remain widely used in industry for cooling circulating water [1] to [3]. In the conventional cooling tower fill acts as the media of heat and mass transfer, by means of which the waste heat is rejected from the system. The effect of the fill is to distribute the water stream and provide a larger surface area for contact between the air and the water. However, fouling of cooling tower fill is one of the most important factors affecting its thermal performance, which reduces cooling tower's efficiency and capability. In the conventional cooling tower, due to salt deposition on the packing and subsequent airflow block, cooling performance of the tower declines after a period of operation time [4] to [5]. On the other hand, the existing of the fill increases the draught drag extremely, which is the main part of power consumption. Eliminating the fill makes the tower fully empty which is of far-reaching significance in cooling the turbid water with high temperature [6]. Application of packed cooling towers to industry is not practical due to salt deposition on the packing and subsequent blockage.

Studies of SCT have been reported sporadically over the years: B.Givoni developed a kind of SCT used for cooling buildings in 1995 [7] to [8], which consists of an open shaft with showers at the top and a collecting pond at the bottom. A pond at the bottom of the shaft collects the sprayed water for recirculation by a small pump. He introduced the system and performed a test to analyze thermal performance. His students tested and compared the performances of this system in three very different climates in another paper. However, they didn't give any theoretical analysis to assist the system. In China SCT attracts many investigators' attention and is becoming a research hotspot these years. But there are no papers presenting a detailed analysis of the cooling characteristics of an SCT.

From the present research status, no systematic theory on studying SCT is available. Most studies are focused on experiments, which deal with many parameters. So perpetual modifications in a great deal of experiments are needed to finalize the results [9]. Furthermore, the investigators barge up against variable problems of technology and theory in the experimental investigation. The fist part includes the movement mechanism of the droplets and the matching of various parameters. In order to solve this problem, the researchers need to carry on large-scale system experiments, which consume a mass of manpower and material resources. Moreover, the flexibility is worse when different experimental results are used to analyze the same problem, because the experimental results cannot conform with the diversification of environment. The other part includes the establishment of mathematical model for SCT. The first part can be solved through solution of the second part. Therefore it is important to establish a reasonable mathematical model of heat and mass transfer for the process of cooling hot water in the SCT, because the results of numerical simulation can guide the experimental research and theoretical analysis.

However, the process of heat and mass transfer between the air and the water in the tower is very complicated. The influence factors include interior structure, the way and the size of spraying water, the environmental factors, the air mass flow rate, wind velocity, the mass flow rate and temperature of inlet water and so on. So the cooling performance has complicated non-linear relationship with these factors, and it is difficult to establish perfect mathematical model for a SCT. The standard method to establish model can obtain some quantity relation that can show the heat and mass performance, but the assumptions are excessive, the process is complicated and the precision is lower.

Exergy is maximum work potential which can be obtained from a form of energy [10] to [11]. Exergy analysis is a useful method, to complement not to replace the energy analysis. Exergy analysis yields useful results because it deals with irreversibility minimization or maximum exergy delivery. Exergy analysis can indicate the possibilities of thermodynamic improvement of the process under consideration. The exergy analysis has proven to be a powerful tool in the thermodynamic analyses of energy systems. Recently, the concept of exergy has received great attention from scientists, researchers and engineers, and exergy concept has been applied to various utility sectors and thermal processes. In general, more meaningful efficiency is evaluated with exergy analysis rather than energy analysis, since exergy efficiency is always a measure of the approach to the ideal.

One important feature of exergy analysis for the system which undergoes a psychrometric process such as in cooling tower operation is that the total exergy can be split into thermomechanical and chemical components, and so it enables one to quantify the contribution of each term on the total exergy through the tower. Shukuya and Hammache [12] expressed that thermomechanical and chemical exergy play an important roles in assessing the actual thermodynamics merit of psychrometric process application. Thirapong Muangnoi [13] used the exergy analysis to explain the performance of conventional cooling tower.

Currently, little is known about the applicability of exergy analysis for shower cooling tower investigation. In this paper, a shower cooling tower performance is predicted by using heat and mass transfer between water and air to drive the solution to steady-state conditions. The second law is used to take account of exergy distributions of water and air in cooling tower. Investigation of the calculated results can be used to further understand details of exergy in shower cooling towers.

1 EXPERIMENT SETUP HEAT AND MASS TRANSFER OF AN SCT

In a SCT, for the sake of computational simplification, when deriving governing equations, the following assumptions were made, which have no evident influences on the cooling result:

1) Heat and mass transfer coefficients are constant within the tower. Both the cool air and hot water have constant physical properties.

2) The vapor pressure in the tower is so low that it has little influence on the pressure through the entire tower. Therefore the average value of atmospheric pressure is used in the calculation.

3) The water droplets moving in the tower are in the shape of ball, and Soter average diameter is assumed as equivalent diameter of the drop.

4) The exterior and interior temperature of the drop is uniform, viz thermal resistance for the water drop is negligible.

5) Lewis factor is equal to 1 [14].

6) Because the whole motion direction of the water droplet is vertical, it is assumed that the water droplet rises or falls vertically in one dimension.

1.1 Mathematical model at the water droplet level

To better investigate the cooling performance of the SCT, it is helpful to first study the heat and mass transfer process at the single water droplet level. This situation is presented schematically in Fig.1. The motion acceleration, turbulence intensity, internal gyration and evaporation of the water droplet have some influences on the motion characteristics in SCT. However, in order to describe the motion characteristics of water droplet in mathematical language, some assumptions concerning the water droplet are made:

As shown in Fig.2, the water droplet is assumed to be spherical and its diameter is small enough so that the temperature of the water droplet can be assumed to be uniform; all water droplets have the uniform diameter and motion tracks; the lesser impact factors such as the possibility of collision or scatteration of the water droplet during the motion process, libration and the ununiformity of internal flow and temperature distribution and so on are ignored in this investigation.

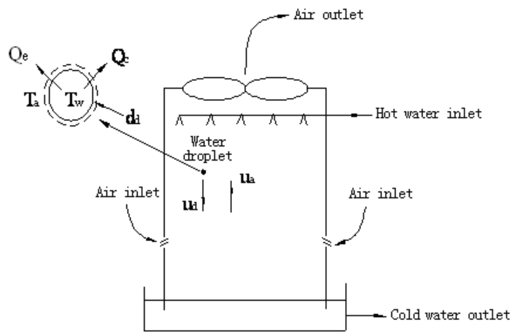

Fig. 1. *Schematic representation of the energy exchange at the water droplet level*

The heat rejected from the water droplets include convective heat and evaporative heat. The water droplet loses heat to the air at the expense of its internal energy, and an energy balance on a control surface surrounding the water droplet yields.

$$\frac{dU_d}{dt} = -(Q_{dc} + Q_{de})\,. \tag{1}$$

Where

$$U_d = m_d c_{pw} T_w\,. \tag{2}$$

$$Q_{dc} = h_c A_d (T_w - T_a)\,. \tag{3}$$

$$Q_{de} = h_d A_d (w_{sw} - w_a) i_v\,. \tag{4}$$

Combining the above equations gives

$$\begin{aligned}\frac{dT_w}{dt} &= -\frac{[h_c(T_w - T_a) + h_d(w_{sw} - w)i_v]A_d}{\rho_w m_d} \\ &= -\frac{6h_d[le_f(i_{masw} - i_{ma}) + (1 - le_f)(w_{sw} - w)i_v]}{c_{pw}\rho_w d_d}\end{aligned}\,. \tag{5}$$

The water evaporation rate, associated with mass transfer, is equal to

$$\frac{dm_d}{dt} = h_d(w_{sw} - w_a)A_d\,. \tag{6}$$

where

$$h_c = Nu_d \lambda / d_d\,. \tag{7}$$

$$\mathrm{Re}_d = (u_d + u_a) d_d / \nu\,. \tag{8}$$

$$\mathrm{Pr} = \mu c_{pa} / \lambda\,. \tag{9}$$

$$Nu = 2 + 0.6\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}\,. \tag{10}$$

$$\begin{aligned}dw_a &= \frac{dm_w}{m_a} = N_d \frac{dm_d}{m_a dt} \\ &= \left(\frac{m_w}{m_a}\right)\frac{h_d(w_{sw} - w_a)A_d}{m_d u_d}\,dz\end{aligned}\,. \tag{11}$$

Refer to Bosnjakovic [8] for a discussion on the derivation and development of the Lewis factor.

1.2 Force analysis of water droplets

In our previous publication, force exerted on a single water droplet was amply analyzed. Only results are used in this work. In the motion process of water droplet sprayed from the nozzle, the forces exerted on the droplet moving with certain velocity include the gravity, G_d, buoyancy from the air, F_d, resistance from the air, R_d. They are expressed as:

Gravity

$$G_d = m_d g = \pi d_d^3 \rho_w g / 6\,. \tag{12}$$

Buoyancy

$$F_d = \pi d_d^3 \rho_a g / 6\,. \tag{13}$$

Drag

$$R_d = \pi C_d \rho_a U^2 d_d^2 / 8\,. \tag{14}$$

According to the motion condition, the drag coefficient, C_d, is expressed as [9]:

$$C_d = 18.5 / \mathrm{Re}^{3/5} \quad 1.9169 \le \mathrm{Re} < 508.3917 \quad \text{(transition flow)}\,. \tag{15}$$

$$C_d = 0.44 \quad \mathrm{Re} \ge 508.3917 \quad \text{(turbulence flow)}\,. \tag{16}$$

Physical definition and Newton's second law of motion is given as

$$u_d = dz / dt\,. \tag{17}$$

$$a_d = \frac{du_d}{dt} = u_d \frac{du_d}{dz}\,. \tag{18}$$

Combining the two equations given above, we obtain the kinetic equation for water droplets in the SCT as

$$\begin{aligned}&\rho_w u_d \frac{du_d}{dz} \\ &= (\rho_w - \rho_a)g - 3C_d \rho_a (u_d + u_a)^2 / 4d_d\end{aligned}\,. \tag{19}$$

1.3 Heat transfer equation in the tower

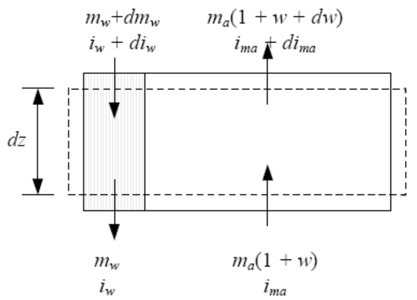

Fig. 2. *Control volume of SCT*

As shown in Fig. 2, energy should be kept balance between the droplet and the air, so the equation can be expressed as:

$$dQ = dQ_c + dQ_e\,. \tag{20}$$

where dQ_c is the sensible heat between the air and the water caused by the temperature difference, which can be expressed as

$$dQ_c = h_c (T_w - T_a) dA \,. \tag{21}$$

dQ_e is the evaporative heat caused by the concentration difference between the saturated vapor around the water droplets and the ambient air which is expressed as

$$dQ_e = i_v h_d (w_{sw} - w_a) dA \,. \tag{22}$$

As the water temperature is T_w, the enthalpy of the water vapor is $i_v = i_{fgw0} + c_{pv} T_w$, and the enthalpy of the saturated water vapor is

$$i_{masw} = c_{pa} T_w + w_{sw} (i_{fgw0} + c_{pv} T_w) \,. \tag{23}$$

Combining the above two equations yields the following equation

$$i_{masw} = c_{pa} T_w + w i_v + (w_{sw} - w) i_v \,. \tag{24}$$

Because the enthalpy of wet air per unit mass of wet air can be expressed as

$$i_{ma} = c_{pa} T_a + w (i_{fgw0} + c_{pv} T_a) \,. \tag{25}$$

Subtracting (25) from (24) yields

$$T_w - T_a = \frac{(i_{masw} - i_{ma}) - (w_{sw} - w) i_v}{c_{pma}} \,. \tag{26}$$

Substituting (26) into (20) yields

$$dQ = \begin{bmatrix} \frac{h}{c_{pma}} (i_{masw} - i_{ma}) + \\ (h_d - \frac{h}{c_{pma}}) i_v (w_{sw} - w) \end{bmatrix} dA \,. \tag{27}$$

Supposing l_{ef} as 1 yields

$$di_{ma} = \frac{dQ}{m_a} = \frac{h_d}{m_a} (i_{masw} - i_{ma}) dA \,. \tag{28}$$

In the cooling tower without fill

$$\frac{di_{ma}}{d_z} = \frac{dQ}{m_a} = (\frac{m_w}{m_a}) \frac{6 h_d}{\rho_w u_d d_d} (i_{masw} - i_{ma}) \,. \tag{29}$$

According to the reference [15], as the relative velocity of the liquid droplet to the air stream is not high (Re<10), it can be regarded as evaporation process for static drop in the air; as the relative velocity of the liquid droplet to the airstream is higher (10<Re<1800), the heat and mass transfer is promoted. Under this condition a few of heat and mass transfer equations were given in the previous references. After comparing the application range, Frossling equations were adopted, whose application range is 10<Re<1800.

As T_a is between ℃0 and 100℃, let $S_c = 0.63$ and substitute the value into equation (11), we can obtain the following:

$$h_d = \frac{\rho_a D_c}{d_d} (1 + 0.276 \, \mathrm{Re}_d^{\,1/2} \, Sc_d^{\,1/3}) \,. \tag{30}$$

$$D_c = \frac{0.0805}{p_a} (\frac{T_a + 273}{273})^{1.8} \times 9.8 \times 10^4 \tag{31}$$

1.4 Numerical solution

In order to study the temperature and heat transfer of the water droplet, we divided the whole motion process z into N finite sections with thickness dz. Section n is filled with water droplets that enter the section at a temperature of $T_{w,n}$ and exit at $T_{w,n+1}$. Consequently, the velocity, the retention time, the height at the outlet of the section n- $u_{w,n+1}$, t_{n+1} and z_{n+1}, respectively differ from the inlet values- $u_{w,n}$, t_n and z_n, respectively. Runge-Kutta method is applied to solve equation (5), (11), (19), (30) and (31), then we can obtain the temperature of the droplets in each differential sections and the outlet water temperature.

2 EXERGY CALCULATION

According to recent definitions, the exergy of a system may be classified as having thermomechanical and chemical exergies. The former may be divided into three types: physical, kinetic and potential exergies. Physical exergy is the maximum amount of obtainable work when the stream is brought, by a reversible process, from its initial state at T and p to a state at T0 and p0 that is in thermal and mechanical equilibrium with environment. The equilibrium state is referred to as the restricted dead state [10]. Most of the time, variations of potential and kinetic exergies can be neglected and hence they are not considered in exergy analysis.

Let each species j reach its partial pressure in the mixture to get chemical equilibrium. The system will obtain its dead state. Therefore, the chemical exergy of a material stream is the maximum achievable work to go from restricted dead state to another dead state. It is said that the system stands at dead state when its pressure, temperature, composition, velocity, or elevation are equal to these corresponding environment parameters.

The total exergy content of a material stream is calculated by summing up these above-mentioned exergies. the specific exergy in psychrometric process—such as in the cooling tower operating mechanism without the effect of kinetic and potential energy at steady state—can thus be generally represented as:

$$ex = ex_{th} + ex_{me} + ex_{ch} . \quad (32)$$

The total exergy consists of three parts: thermalmechanical exergy， ex_{th} ,mechanical exergy， ex_{me} and chemical exergy， ex_{ch} . The three items are represented as

$$ex_{th} = (c_{pa} + \omega c_{pv}) T_0 (\frac{T}{T_0} - 1 - \ln \frac{T}{T_0}) \cdot \quad (33)$$

$$ex_{me} = (1 + 1.608\omega) R_a T_0 \ln \frac{p}{p_0} \cdot \quad (34)$$

$$ex_{ch} = R_a T_0 [(1 + 1.608\omega) \ln \frac{1 + 1.608\omega_{0s}}{1 + 1.608\omega} \cdot \quad (35)$$

So the total exergy can be written as

$$\begin{aligned} X_{air} = m_a [& (c_{pa} + \omega c_{pv})(T - T_0 - T_0 \ln \frac{T}{T_0}) \\ & + (1 + 1.608\omega) R_a T_0 \ln \frac{p}{p_0} \\ & + R_a T_0 (1 + 1.608\omega) \ln \frac{1 + 1.608\omega_{0s}}{1 + 1.608\omega} \\ & + R_a T_0 1.608\omega \ln \frac{\omega}{\omega_{0s}}] \end{aligned} . \quad (36)$$

For determining the rate of exergy destruction I, the loss potential of air to recover exergy supplied by water, can be constructed from the control-volume exergy balance equation. The relation is applied at steady state conditions and undergoes an adiabatic process with no work delivered. Assuming that air–water thermodynamics properties are known at discrete points along the tower height, the exergy destruction for each incremental tower height dz is:

$$\underbrace{[X_{w,z(j+1)} + X_{air,z(j)}]}_{\text{Total exergy entering}} = \underbrace{[X_{w,z(j)} + X_{air,z(j+1)}]}_{\text{Total exergy leaving}} + \underbrace{I}_{\text{Destroyed exergy}} . \quad (37)$$

After rearrangement, the exergy destruction for the discrete height dH will be:

$$\begin{aligned} I = & [X_{w,z(j+1)} - X_{w,z(j)}] \\ & + [X_{air,z(j)} - X_{air,z(j+1)}] \end{aligned} . \quad (38)$$

3 EXPERIMENTAL PROCEDURE

A schematic diagram of an experimental apparatus carrying out in this study is shown in Fig. 1. The tested cooling tower is a mechanical draft-counterflow type where the height of the nozzle can be adjusted from 5m to 8m, the cross sectional area is 10.87m^2. Hot water is pumped from the storage tank which is heated by heaters and controlled by temperature controller, enters cooling tower at top. Water flow rate is adjusted by flow control valve installed next to the pump where its value is read by flow meter. Cooled water exits the tower at bottom and recirculates to the storage tank throughout the test duration. Moist air is induced by fan and enters from bottom, flowing pass the tower, and is finally discharged to the atmosphere at top of the tower. The flow rate is alternatively measured by anemometer for air velocity with known tower cross sectional area. Humidity ratio and dry bulb temperature distributing inside the tower are measured via hygrometer (psychrometer) in which its measuring tip is protected from contacting water. Also, water temperatures distributing inside the tower are measured by thermocouples. Before doing the experiment, water which was collected in storage tank was heated to the desired temperature. Flow control valve was adjusted and the water flow rate was measured. Air velocity was measured at the air inlet. During the experiment, water was uniformly distributed from nozzles, while air was flown upwards. Water temperatures and air conditions were measured after adequate time taken for steady state operating condition. The diameter of the droplets were measured by the intensified high-Speed camera.

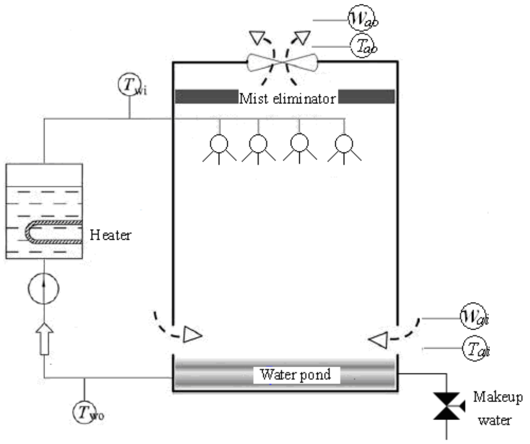

Fig. 3. *Schematic diagram of experimental unit*

4 RESULTS AND DISCUSSIONS

4.1 Model verification

The presented model is validated by using some plant data obtained from Jiangsu Seagull Cooling Tower Co., LTD in China. Table 1 represents the operating conditions and the characteristics of working fluids through the shower cooling tower. The comparative results are the outlet water temperature. It can be noted that the error between the predicted and experimental values are within 10.0%. Thus, this model is agreed in use for predicting the conditions of water and air in shower cooling towers.

Table 1. *Comparison between results of heat and mass transfer model and the experiment data*

Nozzle height (m)	8	6	7
Droplet diameter (mm)	1.1	0.8	0.8
Initial velocity (m/s)	4	6	5
Air velocity (m/s)	2	2.5	2.3
Air to water ratio	0.8	0.9	0.9
Dry-bulb temperature of inlet air(℃)	34	33	34
Humidity ratio of inlet air	0.78	0.7	0.68
Inlet water tempera-ture (℃)	50	44	42
Experimental outlet water temperature(℃)	43.7	37.8	36.2
Computed water temperature based on heat and mass transfer model (℃)	44.3	38.1	36.7
Reletive error (%)	9.52	3.85	8.67

4.2 Exergy analysis

Following the validation of the model, it seems appropriate to evaluate some exergic interactions in the SCT. The atmospheric condition is considered as dead state with dry-bulb temperature 29℃, wet-bulb temperature 21.11℃, pressure p=100.4kPa. The sectional area of the tower is 10.87m^2, and the height of the nozzle is 5m, the water mass flowrate is 55.21m^3/h, the air mass flowrate is 44206m^3/h.

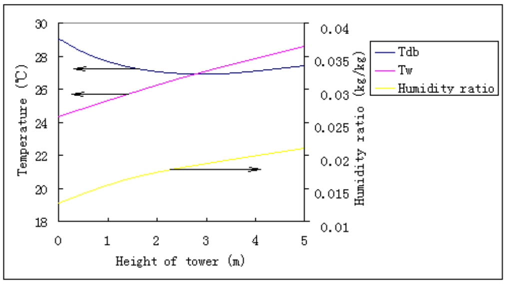

Fig. 4. *Temperature profiles of water and air, and humidity ratio profile through the shower cooling tower*

Fig. 4 is a plot of the water temperature, the dry-bulb temperature and the humidity ratio of the air versus height of tower. The water falls from the top and its temperature, Tw, decreases continuously as it approaches the bottom of the tower. This is generally expected in a shower cooling tower because the water loses heat both by convection and evaporation. It is interesting to see that the air, which enters from the bottom of the tower with initial dry bulb temperature, Tdb, decreases in temperature and then increases before leaving from the top of the tower. This can be explained from the fact that the water, which enters from the top of the tower, when it reaches the lower part, is cooled because of a predominantly evaporation mechanism. In this region, the water temperature, Tw, is much lower than the entering air dry bulb temperature, Tdb, however, as we note from Fig.3, when the tower height from the top reaches above 2.9m, the water temperature is less than Tdb. This results in heat transfer from the air to the water (i.e. negative convection). The intersection point of the Tdb and Tw curves indicates no temperature difference. At this point, there is no convection heat exchange between the water and the air. Furthermore, below this point Tdb is less than Tw, which results in heat transfer from the water to the air (i.e. positive convection).

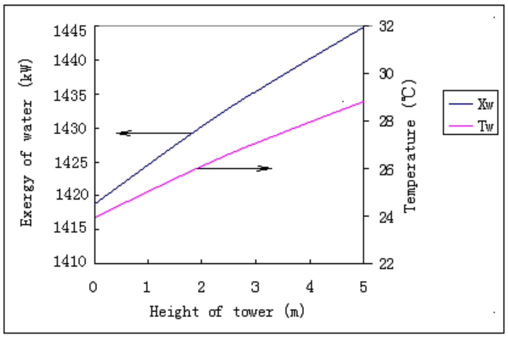

Fig. 5. *Exergy of water and water temperature profiles through the shower cooling tower*

Fig. 5 is a plot of water exergy, Xw, and water temperature, Tw, versus height of tower. As same as the conventional cooling tower [13], water exergy defined as the available energy carried by supplying water decreases continuously from top to bottom. It can also be explained from the fact that water temperature decreases from top to bottom as a result of supplying its exergy to air.

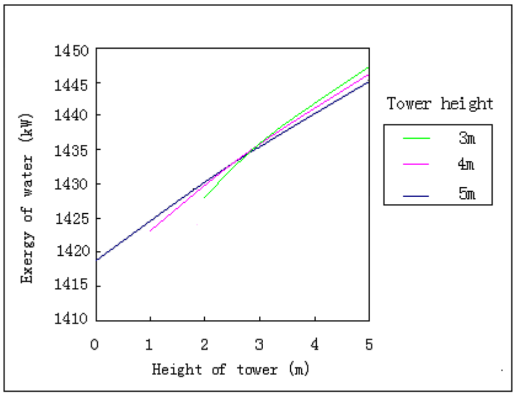

Fig. 6. *Effect of the tower height on water exergy through the shower cooling tower*

The effect of the tower height on exergy of water through the SCT is shown in Fig.6. As the tower height gets larger, the exergy of water gets less, because the heat and mass transfer rate from the water to the air is larger. The exergy of water suppled to the air is less with the less height.

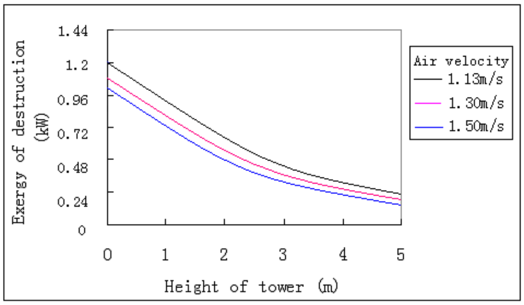

Fig. 7. Effect of air velocity on exergy destruction through the SCT (diameter is 15mm)

The exergy destruction is represented by the difference between exergy change of water and exergy change of air. Fig.7. has illustrated the exergy destruction along the SCT for three air velocities. It is indicated the distribution of the exergy loss is high at the bottom and gradually low at the top of the tower. Hence, minimum exergy destruction is accomplised at the top for each air velocity. Moreover, it shows that 1.50m/s air velocity is resulted in less exergy destruction. This is due to large transfer from water to air.

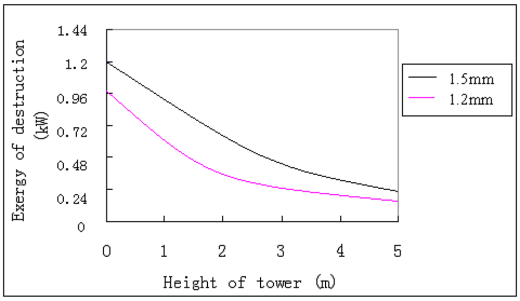

Fig. 8. *Effect of size of water droplets on exergy destruction through the SCT*

The effect of size of water droplets on exergy destruction through the SCT is shown in Fig.8. It can be described that, for example, 1.19 kW of exergy destruction is destroyed when the tower bottom height is changed from 0.00m to 0.56m. Furthermore, another 0.876kW of exergy destruction is also destroyed when the tower height is changed from 0.56m to 1.12m, and so on. These distributions of exergy destruction indicate that these are high at bottom and gradually low at the top. The minimum value locates at the top. Fig. 8 also shows the effect of water droplets diameter on the overall exergy destruction. Obviously, with a decrease in the water droplet, the fluids carrying energy have more opportunities for mass and energy transfers. Highly intensive mass and energy interactions are always gone with thermodynamic irreversibilities and entropy production which result in increasing in exergy destruction.

5 CONCLUSIONS

In this study energy and exergy analysis are carried out on shower cooling tower based on mathematical modeling and simulation results. The method was validated using experimental data. In fact, the irreversibilities of any process destroy some inlet exergies. Also, the results show that the exergy of water is not completely absorbed by air and a notable portion of the exergy is always destroyed, much more in the bottom sections. The exergy analysis depicts that exergy destruction increases with increasing water droplets diameter.

Water exergy defined as the available energy carried by water to be supplied decreases continuously from top to bottom. For the air side, its exergy means the available energy of air to recover or utilize that supplied by water. There are two kinds of exergy in air that are due to exergy of air via convective heat transfer and exergy of air via evaporative heat transfer. Exergy destruction is high at the bottom and reducing at the top. 1.19 kW of exergy destruction is destroyed when the tower bottom height is changed from 0.00m to 0.56m. Furthermore, another 0.876kW of exergy destruction is also destroyed when the tower height is changed from 0.56m to 1.12m, and so on. The distributions of exergy destruction can be used as a guideline to find optimal potential for improving cooling tower performance. With the dropping of the water droplets to the bottom, the droplets velocity increase rapidly, which means the heat and mass transfer process between water with fresh air is extremely short. So the useful energy delivered from water to air reduces, that is, the exergy destruction increases. For shower cooling tower, it is an important constraining factor.

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