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Performance of the Volumetric Mass Transfer Coefficient in a Cooling Tower

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Abstract

In this work, it is presented the design of a laboratory scale cooling tower with wood splash type packing to make an experimental study on terms of the volumetric mass transfer coefficient (kya), water to air flow ratio (L/G) and inlet water temperature. The performance of the tower was evaluated at different mass flow ratios of water to air (L/G) in the range from 0.22 to 1.1, and water inlet temperature from 40°C to 48°C. It was found that the tower efficiency had an exponential decay when the mass rate ratio of liquid to gas L/G increases. The volumetric mass transfer coefficient behaves different in two zones of L/G ratios.

The values of kya decrease when the water inlet temperature increases for low values of L/G in the range from 0.22 to 0.66. This effect decreases for high values of L/G. The effect of the inlet water temperature in the efficiency is negligible.

Keywords: Cooling tower, efficiency, tower packing

1. Introduction

Generally big industries such as the chemical and petrochemical industry as well as laboratories of unit operations in universities that offer Chemical and Mechanical Engineering in their curriculum use cooling towers to remove a great amount of heat for treating recirculated water required for condensers, heat exchangers and other process equipment. To improve the performance of these towers different types of packing are placed inside to increase the contact area between the liquid and the gas [1-3], generally water and air. One important parameter directly related with the tower packing is the volumetric mass transfer coefficient kya which most of the time is taken constant [4] when operating the towers. However, it has been demonstrated that kya is not constant and depend on the operating conditions of the system. It can be seen in an experimental investigation of a direct contact evaporative cooling tower filled with a “VGA” type packing [5], and the correlations of loss coefficient for wet-cooling tower [6].

Even when different model has been proposed, they do not work for all the towers. Every model function only for their own system. In fact, if the system gets out of their operating zone the models present error because of data extrapolation. For this reason, it is necessary to make more studies in the area in order to have a complete understanding of the phenomena happening inside the cooling tower.

In this work, a cooling tower was built on a laboratory scale with wood splash type packing to study the effect of the inlet water temperature and ratio L/G on the volumetric mass transfer coefficient kya. The packing was sized according to the design parameters found in the work of Mohiuddin AKM et al., 1996 [7]. It was found that the values of kya remain almost constant when the ratio L/G was in the range from 0.22 to 0.66. However, for values of L/G higher than 0.6, the values of kya tend to increase linearly. It indicates that different models can be created for different L/G ranges.

2. Methodology

The experiments were performed in a cooling tower with the dimensions shown in table 1. The hot liquid water at 48^{o}C enters at the top of the tower while the cool air enters at the bottom of the tower.

Table 1. Dimensions of the packed cooling tower

Parameter		Parameter	
Number of decks splash type	4	Total packing height	1,20 m
Vertical deck spacing splash type	0,40 m	Total height of the tower	1,60 m
Number of decks film type	3	Width of the tower	0,15 m
Vertical deck spacing film type	0,20 m	Length of the tower	0,15 m

The material of the splash type packing was wood which have a thermal conductivity of 0.13 W/m.K. The shape of the splash packing is shown in figure 1.

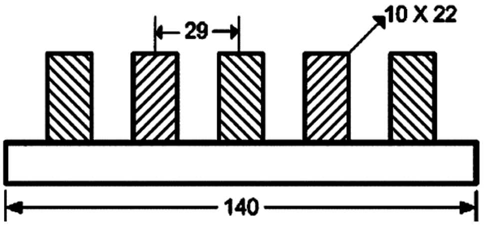

Figure 1. Dimensions (in mm) of the splash type packing designed according to the parameters given by A. K. M. Mohiuddin and K. Kant, 1996.

The fixed operating conditions are shown in table 2.

Tabl**e** 2. Operating conditions

Parameter	**Valor**
Inlet water Temperature (T_{L2})	48°C
Inlet air dry bulb temperature (T_{BS1})	26.2°C
Inlet air wet bulb temperature (T_{BS2})	22.4°C
Volumetric flow of water, gpm	[1; 0.8; 0.6; 0.4; 0.2]
Mass rate of dry air	205.23 Kg/h
Inlet enthalpy of the air, hy_1	65.81 KJ/Kg

2.1 Equations

Figure 2 shows the scheme of the system with all the parameter used for the mass and energy balances. Dry air enters to the tower increasing its humidity along with the height of the tower because of the water evaporated from the hot liquid. It was made a differential energy balance (see Eq. 1) to build the operating line in the differential control volume shown in figure 2, where C_L is the specific heat of the liquid which is considered constant in the range of temperature of this system.

$$L^{'}C_L dT = G_S^{'} dh_y \tag{1}$$

With the integration of equation 1 it is obtained the operating line of the system. The total heat transfer in the differential control volume is determined with the total energy gained by the air, which is the sum up of the latent heat and the sensible heat, see equation 2.

$$G_S^{'} dh_y = \lambda_o \left(H_i - H_G\right) k_y a_M M_B dz + \quad h_G a_H \left(T_i - T_G\right) dz \tag{2}$$

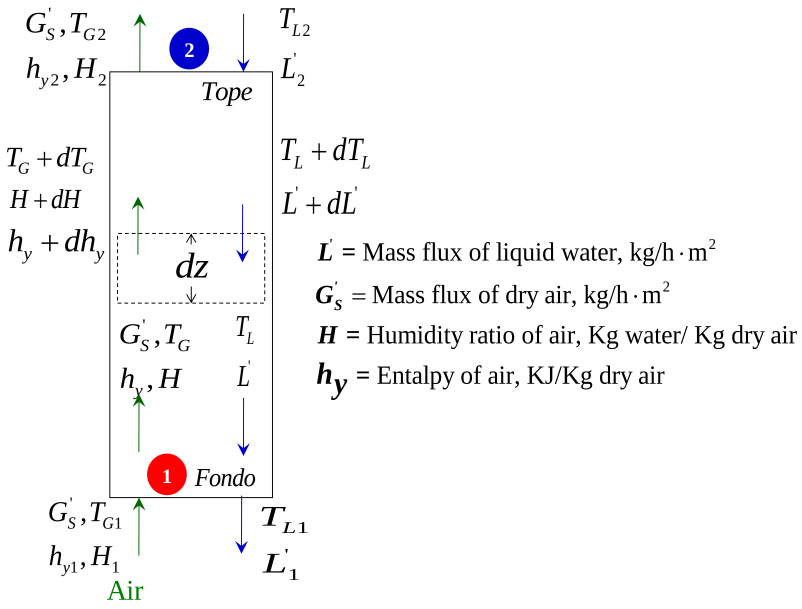

Figure 2. Scheme of the cooling tower

Where $k_y a$ is the volumetric mass transfer coefficient of the system, and M_B is the molecular weight of the air, λ_o is the latent heat of the water, $h_G a_H$ is the volumetric heat transfer coefficient of the ar, H_i is the air humidity at the interface, H_G is the air humidity in the bulk, T_i is the air temperature at the interface, and T_G is the air temperature in the bulk.

After some algebraic manipulations of equation 2, it is obtained the equation 3 to determine the size of the tower.

$$Z = \frac{G_S'}{k_y a M_B} \int_{h_{y1}}^{h_{y2}} \frac{dh_y}{\left(h_{yi} - h_y\right)} \qquad (3)$$

3. Results and Analysis

The results were obtained running the experiments with the operating conditions shown in table 2.

3.1 Effect of the ratio L/G on the volumetric mass transfer coefficient

Figures 4 shows the variation of the volumetric mass transfer coefficient (kya) for different values of the ratio L/G. The kya always increases when L/G increases. It means that as the mass rate of liquid water increases for the same amount of air, the mass transfer of evaporated water to the gas increases helping in the performance of the tower. Figure 4 shows two lines with the same trend to increase. The yellow line was obtained by solving the system by energy balances considering negligible the amount of water evaporated. The red operating, which was named real, was obtained using the air parameters taken at the outlet of the tower. It means that low performance results were obtained theoretically, while high performance was obtained with the experimental data of the air parameters. The kya obtained with real experimental data increases 383% regarding the kya obtained with energy balances when L/G=0.22. This increase was 367% when L/G=1.1.

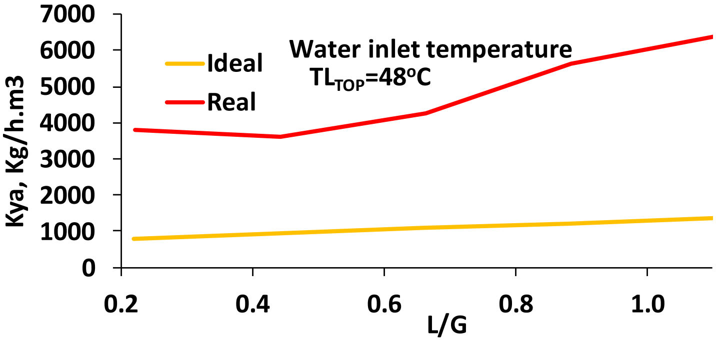

Figure 3. Behavior of the volumetric mass transfer coefficient as a function of L/G at 48°C

Figures 5 a and b show the saturation curve of the air with the operating line of the cooling tower for the following conditions, L/G [0.2; 1.1], T_{BS1}=26.2°C, T_{BH1}=22.4°C, T_{L2}=48°C. This plot corroborates the information obtained in figure 4. In both plots the real operating line approximates to the saturation curve indicating higher real contact mass water. This effect is higher for high ratios of L/G. Considering that both plots have the same scale, it can be seen that the driving force for enthalpy is higher when L/G=1.1 than for L/G=0.22. It means that better results were obtained for L/G=1.1 if the height of the tower were a little higher.

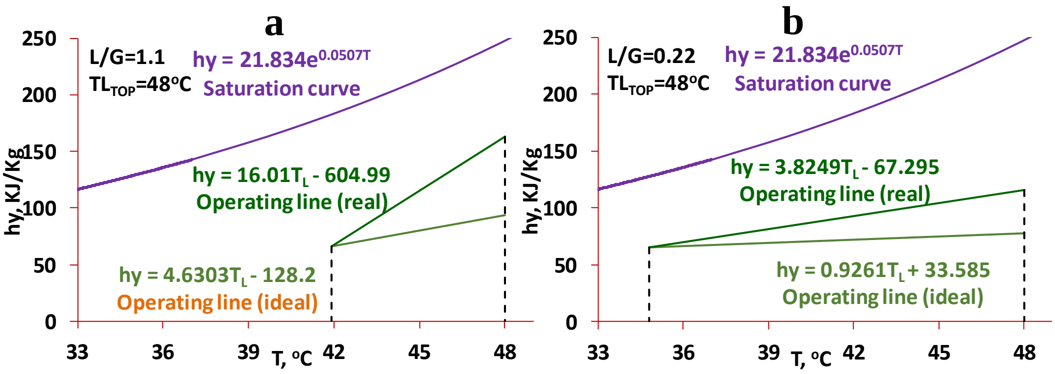

Figure 4. Operating line behavior when using wood splash type packing in the cooling tower for a) L/G=1.1 and b) L/G=0.2

3.2 Effect of the inlet water temperature and ratio L/G on the volumetric mass transfer coefficient kya

Figures 6 a and b show the behavior of kya for different values of the ratio L/G and different inlet water temperatures. Figure 6 shows the same trend as figure 4 when experiments were run at different inlet water temperatures. The values of kya always increase as the ratio L/G increases. However, this effect is higher at low values of inlet water temperatures. The values of kya tend to decrease when the water inlet temperature increases for low values of L/G in the range from 0.22 to 0.66. This effect decreases at high values of L/G.

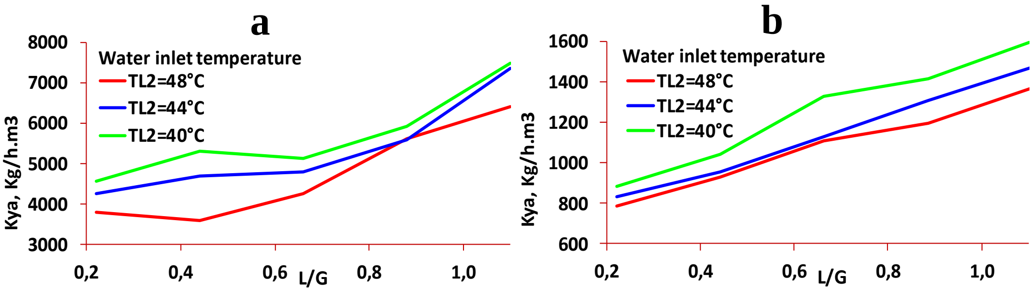

Figure 5. Variation of kya as a function of L/G for different water inlet temperatures using a) experimental data at the outlet of the air, and b) outlet air parameters obtained by energy balances

Similar to figure 4, the values of kya were obtained using experimental data at the outlet of the air (figure 6a) and using the outlet air parameters obtained by energy balances (figure 6b). In figure 6a it can be seen that for values of L/G in the range from 0.22 to 0.66 the values of kya tend to remain constant. For values of L/G higher than 0.6, the values of kya tend to increase linearly. This pattern was the same for all the inlet water temperatures.

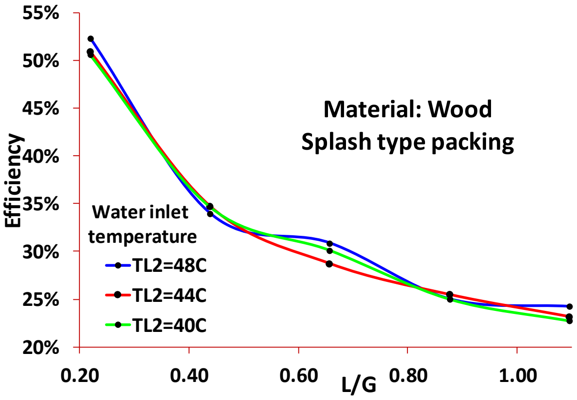

Figure 6. Behavior of the cooling tower efficiency as a function of L/G for different inlet water temperatures

Comparing the results of kya obtained with the calculated data and those obtained with the experimental data it can be seen increments in kya around 400%. It validates the results of figure 4 indicating that the tower presents a better performance than the calculated theoretically.
Figures 7 shows the behavior of the cooling tower efficiency for different values of the ratio L/G and different temperatures. As can be seen the efficiency decreases more than half of its maximum value when L/G increases from 0.22 to 1.1. The effect of the inlet water temperature in the efficiency is negligible.

4. Conclusions

In the present work, it was studied the performance of the volumetric mass transfer coefficient of a cooling tower under different operating conditions using wood as splash type packing. It was found that the values of kya remain almost constant when the ratio L/G was in the range from 0.22 to 0.66. However, for values of L/G higher than 0.6, the values of kya tend to increase linearly. The results of kya determined using the outlet air parameters obtained by real experimental data increase 383% regarding the kya results obtained with energy balances when L/G=0.22. The increase was 367% when L/G=1.1. The driving force for evaporation of the water is higher when L/G=1.1 than for L/G=0.22. The values of kya decrease when the water inlet temperature increases for low values of L/G in the range from 0.22 to 0.66. This effect decreases for high values of L/G. The tower efficiency decreases more than half of its maximum value when L/G increases from 0.22 to 1.1. The effect of the inlet water temperature in the efficiency is negligible.

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