Influence of the mass flow ratio water-air on the volumetric mass transfer coefficient in a cooling tower

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Abstract: A laboratory scale mechanical draft cooling tower with acrylic film type packing was studied. The performance of the tower was assessed at different mass flow ratios of water to air L/G , maintaining constant the water and air inlet temperatures and the packing material. It was found that the relation of the volumetric mass transfer coefficient $k_y a$ versus the volumetric heat transfer coefficient $h_L a$ is not affected by the operating conditions. The small differences obtained are due to the experimental error. For all the value of the ratio L/G in the range of $k_y a/h_L a$ [3,25] the assumption of $k_y a/h_L a = \infty$ cannot be considered and the relation has the following expression $k_y a = 624.76(h_L a)^{0.34}$. However, for $k_y a/h_L a > 25$ the assumption of $-m = \infty$ is valid, and the value of $k_y a$ is approximately 2800 Kg/h.m³.

Keywords : Cooling tower, efficiency, tower packing, volumetric mass transfer coefficient.

1. Introduction

Cooling towers are important refrigeration systems used in many different kinds of industries around the world. Their advantage consists in the direct contact gas-liquid that cause a better heat transfer rate¹. This advantage is improved with the use of packing towers that increase the contact area gas-liquid^{2,3}. Many different geometries and arrangements of the packing have been created to enhance the performance of the cooling towers⁴. Every packing has an impact in the volumetric mass transfer coefficient which is the most important parameter used to model the behavior of the towers. There are other parameters that affect the volumetric mass transfer coefficients such as the inlet temperatures of the fluids. There has been lots of research focusing on enhancing the performance of the cooling towers studying the parameters that have the highest influence on heat and mass transfer. It was done a study of the effect of the tower height to base diameter ratio in the performance of a cooling tower⁵ by means of CFD simulations. Muangnoi et al., 2014, studied the relationship of water-jet cooling tower approach temperature, heat rejection load, wet-bulb temperature, water to air ratio, tower spray zone height, droplet diameter, discharge droplet velocity and air velocity in a cooling tower to

improve system operation⁶. Mirabdollah et al., made an experimental investigation of the thermal performance characteristics of a direct contact counter flow wet cooling tower filled with rotational splash type packing⁷. Lowe studied the mass transfer coefficients as a function of L/G ⁸ while Kloppers and Kröger⁹ studied the same parameter as a function of mass liquid rate and gas rate separately.

In this work, a laboratory scale mechanical draft cooling tower with acrylic film type packing was studied. The packing was sized according to the design parameters found in the work of Mohiuddin AKM et al., 1996¹⁰. The performance of the tower was evaluated at different mass flow ratios of water to air L/G , maintaining constant the water and air inlet temperatures and the packing material. It was found that the relation L/G has a significative effect on the outlet air temperature and in the efficiency of the tower. No effect was found in the volumetric mass transfer coefficient.

2. Methodology

The experiments were performed in a cooling tower where the hot liquid water at 48°C enters at the top of the tower while the cool air enters at the bottom of the tower at a dry bulb temperature of 26.2°C and wet bulb temperature of 22.4°C. Figure 1 shows a scheme of the system with the main parameters used to make the mass and energy balance.

Figure 1. Sketch of the cooling tower

Figure 1 shows that dry air enters in the bottom of the tower and as it rises, its humidity increases because of the evaporation caused by the contact air-water. This contact is increased by the use of film type packing tower making the liquid water to decrease the temperature. The total height of the tower was 1.41 m and contain three decks film type inside. The space from deck to deck was 0.35 m and the transversal area of the column was $0.15 \times 0.15 \text{ m}^2$. The material of the film type packing was acrylic. The shape of the film type packing is shown in figure 2. It was used a digital anemometer to determine the velocity of the air, a rotameter to measure the flow rate of the liquid water, and a set of temperature sensors to measure the temperature of the air as well as its physical properties.

Figure 2.Dimensions (in mm) of the film type packing designed according to the parameters given by A. K. M. Mohiuddin and K. Kant, 1996.

It was used the relation L/G with the following values [0.44; 1.11; 1.88] obtained varying only the mass flux of liquid water. With the given inlet temperatures of the air, it was obtained the inlet enthalpy, $h_{y1}=65.81$ KJ/Kg, and the relative humidity of 72.34%. The outlet relative humidity of the air obtained was 98%. As can be seen, the air gets out almost saturated with water indicating that the tower has a good heat and mass transfer. The efficiencies of the tower with these operating conditions were [25%, 40%, 67.2%]. The air enthalpy at the top h_{y2} was obtained using the Eq. 1 which is the energy balance of the cooling tower considering no loss of heat to the surroundings.

$$\dot{L}C_L(T_L - T_{L0}) + \dot{G}_S h_{y1} = \dot{L}C_L(T_{L1} - T_{L0}) + \dot{G}_S h_y \quad (1)$$

where C_L is the specific heat of the liquid which is considered constant in the range of temperature of this system. The subscript 1 refers to the bottom of the column.

Considering negligible the amount of water evaporated it is obtained Eq. 2

$$\dot{G}_S (h_y - h_{y1}) = \dot{L}C_L (T_L - T_{L1}) \quad (2)$$

This equation represents the operating line of the cooling tower. With Eq. 2 and the saturation line air-water, it is plotted figure 3. The outlet dry bulb temperature of the air T_{G2} was obtained with the Mickley method.

Figure 3.Characteristic operating line of the system

Figure 3 helps to understand if the system is working adequately and if the air used is getting saturated or not. The building of the tower was made considering the Merkel equation.

$$Z = \frac{G'_S}{k_y a} \int_{h_{y1}}^{h_{y2}} \frac{dh_y}{(h_{yi} - h_y)} \quad (3)$$

where $k_y a$ is the mass transfer coefficient of the system. The subscript 1 refers to the interface water-air.

3. Results

Figures 4 shows the saturation curve of the air with the operating line of the cooling tower for the relation $L/G = [0.44; 1.11; 1.88]$. As can be seen, there are three different operating lines, figure 4a, b and c that correspond to the given ratios of L/G . The slopes of the operating line increase as the ratio L/G increases.

Figure 4. Behavior of the operating line as a function of L/G using acrylic film type packing a) $L/G=0.44$, b) $L/G=1.11$, c) $L/G=1.88$

Figure 5a shows that the outlet air temperature increases as L/G increases. It happens because there is a higher amount of liquid in contact with the gas causing a higher heat transfer rate resulting in an increase in the temperature of the air. This relation is not linear and has a tendency to the inlet temperature of the liquid. Figure 5b shows that the efficiency of the column decreases as L/G increases because there is a higher amount of water to cool using the same amount of air. It causes a decrease in the capacity of cooling of the tower. It has a hyperbolic behavior which tends to zero.

Figure 5. Effect of the ratio L/G on the a) outlet air temperature and b) efficiency of the cooling tower using acrylic film type packing.

Figure 6 shows the behavior of the operating line when the ratio of the volumetric mass transfer coefficient to the volumetric heat transfer coefficient changes to 200 when $L/G = 1.88$. As can be seen, even for a large change in the value of $-m$, the outlet air temperature remains the same. It means that there is a direct relation between the $k_y a$ and $h_L a$.

Figure 6. Behavior of the operating line when $-m = 200$ at $L/G = 1.88$

As mentioned before, there is a relation between the $k_y a$ and $h_L a$. This relation is shown in figure 7 for values of the ratio $L/G = [0.44; 1.11; 1.88]$. It can be seen that there is no effect on the operating conditions in the relation $k_y a$ vs. $h_L a$. For a large range of $-m$ for any value of L/G , the relation $kyavs-m$ remain constant. The small difference is due to the fact that they are experimental data. That is the corresponding error. Considering that the lines obtained practically do not suffer variation, the relation $kyavs-m$ remains constant. However, if it is changed the packing tower, the area, or the height of the tower, this relation changes.

Figure 7. Behavior of the cooling tower efficiency as a function of L/G for different materials of the splash type packing.

Figure 8 shows the same plot 7 in a shorter range. In this range the assumption of $-m = \infty$ cannot be taken because the gas phase and the liquid phase have the similar strength on the heat resistance. It means that for a given tower the relation Ky_{av} - m can be obtained with simple experiments of changing the operating conditions. However, if the physical parameters of the tower changes, the function obtained changes.

Figure 8. Behavior of the cooling tower efficiency as a function of $-m$ for different ratios of L/G

For all the value of the ratio L/G , in the range of $-m$ [3,25] the assumption of $-m = \infty$ cannot be taken because the gas phase and the liquid phase have the similar strength on the heat resistance. In this range, the lines have the following regression: $k_y a = 624.76 (h_L a)^{0.34}$. However, for $-m > 25$ the assumption of $-m = \infty$ is valid, and the value of $k_y a$ would be approximately 2800 Kg/h.m³.

4. Conclusions

In the present work, it was studied the performance of a cooling tower under different ratios of L/G with the use of film type packing. It was found that the slopes of the operating line increase as the ratio L/G increases causing an increase in the outlet wet dry temperature of the air due to the higher amount of liquid in contact with the gas causing a higher rate of heat transfer. The relation between the outlet wet dry air temperature and L/G is not linear and has a limit to the inlet temperature of the liquid. This behavior makes the efficiency of the

column to decrease as L/G increases because there is a higher amount of water to cool using the same amount of air. It causes a decrease in the capacity of cooling of the tower. It has a hyperbolic behavior which tends to zero. It was found that the relation $ky_{avs}-m$ is not affected by the operating conditions.

For all the value of the ratio L/G , in the range of $-m$ [3,25] the assumption of $-m=\infty$ cannot be considered because the gas phase and the liquid phase have the similar strength on the heat resistance. However, for $-m>25$ the assumption of $-m=\infty$ is valid.

References

1. Obregon, L.G., J.C. Pertuz, and R.A. Dominguez, *Performance analysis of a laboratory scale cooling tower for different packing materials, water inlet temperature and mass flow ratio water-air*. Revista Prospectiva, 2017. 15(1): p. 42-52.
2. Gharagheizi, F., R. Hayati, and S. Fatemi, *Experimental study on the performance of mechanical cooling tower with two types of film packing*. Energy Conversion and Management, 2007.48(1): p. 277-280.
3. Goshayshi, H.R. and J.F. Missenden, *The investigation of cooling tower packing in various arrangements*. Applied Thermal Engineering, 2000.20(1): p. 69-80.
4. Shahali, P., et al., *Experimental study on improving operating conditions of wet cooling towers using various rib numbers of packing*. International Journal of Refrigeration, 2016.65: p. 80-91.
5. Liao, H.T., et al., *Influences of height to diameter ratios of dry-cooling tower upon thermo-flow characteristics of indirect dry cooling system*. International Journal of Thermal Sciences, 2015.94: p. 178-192.
6. Muangnoi, T., W. Asvapoositkul, and P. Hungspreugs, *Performance characteristics of a downward spray water-jet cooling tower*. Applied Thermal Engineering, 2014.69(1): p. 165-176.
7. MirabdollahLavassani, A., et al., *Experimental study on the thermal performance of mechanical cooling tower with rotational splash type packing*. Energy Conversion and Management, 2014.87: p. 530-538.
8. Lowe, H.J. and D.G. Christie, *Heat transfer and pressure drop data on cooling tower packings, and model studies of the resistance of natural draft towers to airflow*, in *International Heat Transfer Conference*. 1961, New York: American Society of Mechanical Engineers, 1963.: Colorado. p. 933-950.
9. Kloppers, J.C. and D.G. Kroger, *Loss coefficient correlation for wet-cooling tower fills*. Applied Thermal Engineering, 2003.23(17): p. 2201-2211.
10. Mohiuddin, A.K.M. and K. Kant, *Knowledge base for the systematic design of wet cooling towers. Part II: Fill and other design parameters*. International Journal of Refrigeration, 1996.19(1): p. 52-60.