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Parametric study of a laboratory scale cooling tower for different packing materials, and mass flow ratio Water-Air

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Abstract : This work deals with the design of a laboratory scale cooling tower. Different materials of splash type packing were used, wood, acrylic plastic, iron and aluminum, as well as a film type packing made of acrylic material. The performance of the tower was assessed at different mass flow ratios of water to air, water inlet temperature and different packing materials of the tower. It was found that the tower efficiency decreases when the mass rate ratio of liquid to gas L/G increases. The tower efficiency decreases when the inlet water temperature decreases implying that the tower has a better performance when cooling water at high temperatures. High values of thermal conductivities in the packing results in low tower efficiencies. Low thermal conductivity materials ($K<0.2 W/m^oC$) increase the tower efficiency around 4.9% to 9.3% when compared with high thermal conductivities materials ($K>80.2 W/m^oC$), operating the tower in the range of L/G from 0.22 to 1.1.
Keywords : Cooling tower, efficiency, tower packing.

1. Introduction

Most of the chemical and petrochemical industry needto remove a great amount of heat generated from many types of equipment to operate efficiently. The heat transfer equipment most commonly used are heat exchangers and condensers. The most practical and economical way to achieve itis through the use of packed cooling towers, as they offer important advantages because of the direct contact between the fluids. The effectiveness of the towers is because they can increase the surface contact area between the fluids with the use of different tower packing, intensifying the transport of mass and energy. At present, there are three types of packaging that are the most used, which are film, splash and mesh-film [1].

Lots ofexperimental research has been done tooptimize the performance of the cooling towersstudying the parameters that have the highest influence on heat and mass transfer, especially the type of packaging. An

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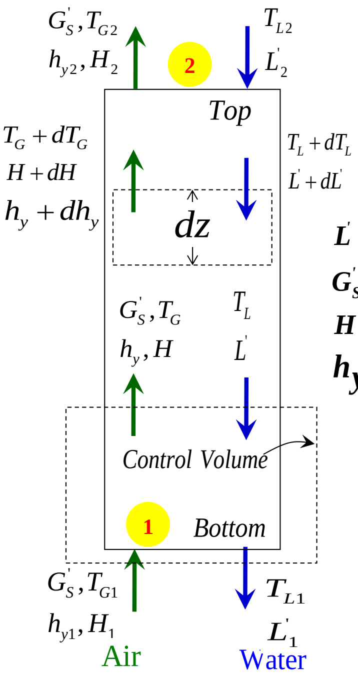
experimental and a comparative study was maderegarding tower characteristics (KaV/L), water to air flow ratio (L/G) and efficiency for two type of packings [2]. Goshayshi and Missenden studied the mass transfer and pressure drop characteristics of many types of corrugated packing, including smooth and rough surface corrugated packings [3].Mirabdolahet al., made an experimental investigation of thermal performance characteristics of a direct contact counter flow wet cooling tower filled with rotational splash type packing [4].Lowe [5]studied the mass transfer coefficients as a function of L/G while Kloppers and Kröger [6]studied the same parameter as a function of mass liquid rate and gas rate separately. Kloppers and Kröger [7] noted as well that the transfer coefficient also depended on the height of the packing, and the variation of the inlet temperature.

Although the results of the different experiments are highly valuable, they have been very specific about the type of packaging material, so in this work, a cooling tower was built on a laboratory scale with splash typepacking with four different materials: wood, acrylic plastic, aluminum, iron. A film type packing made of acrylic plastic was studied as well to compare the results with the acrylic splash packing. The packings were sized according to the design parameters found in the work of Mohiuddin AKM et al. [8]. It was found the effect of the ratio L/G on the cooling tower efficiency at different inlet water temperatures and the behavior of the cooling tower efficiency for different packing materials.

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. The packing of the tower mentioned in table 1 help to increase the mass and heat transfer area.Figure 1 shows a scheme of the system.



L' = Mass flux of liquid water, kg/h·m^2

G_S' = Mass flux of dry air kg/s·m^2

H = Humidity ratio of air, Kg water/Kg dry air

h_y = Entalpy of air, KJ/Kg dry air

Figure1.Scheme of the system

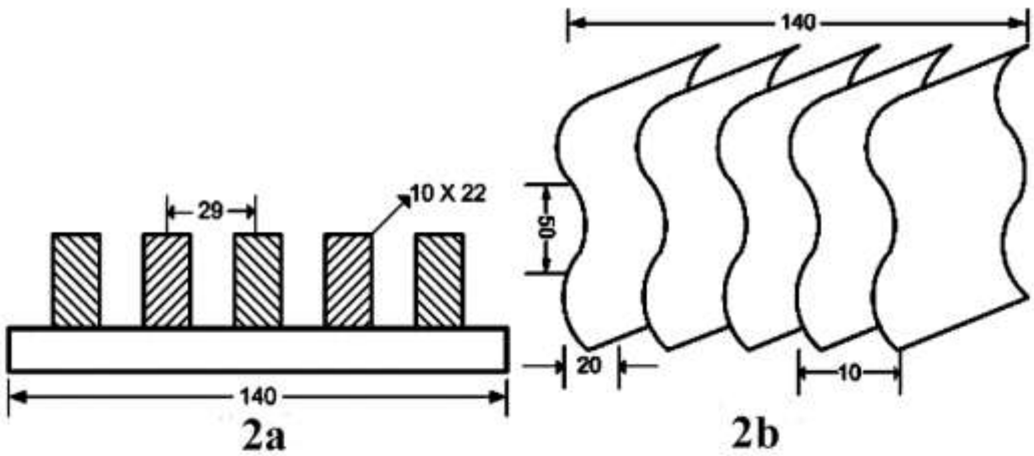
As can be seen in figure 1, dry air enters the tower,and as soon it goes to the top begin to increase the humidity with the water being evaporated from the hot liquid. This contact makes the liquid water to decrease the temperature.

Table1. Dimensions of the packed cooling tower

Parameter	**Dimension**	**Parameter**	**Dimension**
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 materials of the splash type packing were aluminum, iron, wood, and acrylic. The material of the film type packing was acrylic. The shape of the splash and film packing are shownin figure 2a and b.

Figure2.Dimensions (in mm) of the splash type packing (a) and film type packing (b), designed according to the parameters given by A. K. M. Mohiuddin and K. Kant, 1996. [8]



The fixed operating conditions are shown in table 2.

Table2. Operating conditions

Parameter	**Valor**
Inlet water Temperature (T_{L2})	48°C
Inlet air dry bulb temperature (T_{BS1})	26°C
Inlet air wet bulb temperature (T_{BS2})	22°C
Volumetric flow of water, gpm	[1;0.8;0.6;0.4;0.2]
Mass rate of dry air	207.21Kg/h
Inlet enthalpy of the air, hy_1	64.32 KJ/Kg

The thermal conductivities of the materials of the tower packing are shown in table3.

Table3.Thermal conductivities of the packing materials

Material	***K*, Thermal conductivity (W/K m)**
Acrylic	0.2
Aluminum	209.3
Iron	80.2
Wood	0.13

The equipment used to measure the parameters are shown in table 4.

Table 4. Cooling tower instruments

Instruments	Range	Design Temperature
Digital anemometer	0-30 m/s	45°C
Temperaturesensors	0-100 °C	100°C
Rotameter	0-9.46 L/min	60°C

2.1. Equations

It was made an energy balance (see Eq. 1) to build the operating line. It was done considering the control volume shown in figure 1, where C_L is the specific heat of the liquid which is considered constant in the range of temperature of this system.

$$L'C_L\left(T_L - T_{L0}\right) + G'_S h_{y1} = L'_1 C_L\left(T_{L1} - T_{L0}\right) + G'_S h_y \quad (1)$$

The subscript 1 refers to the bottom of the column. Considering negligible the amount of water evaporated it is obtained Eq. 2

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

Eq. 2 correspond to the operating line of the cooling tower. With Eq. 2 and the saturation line air-water, it is plotted figure 3.

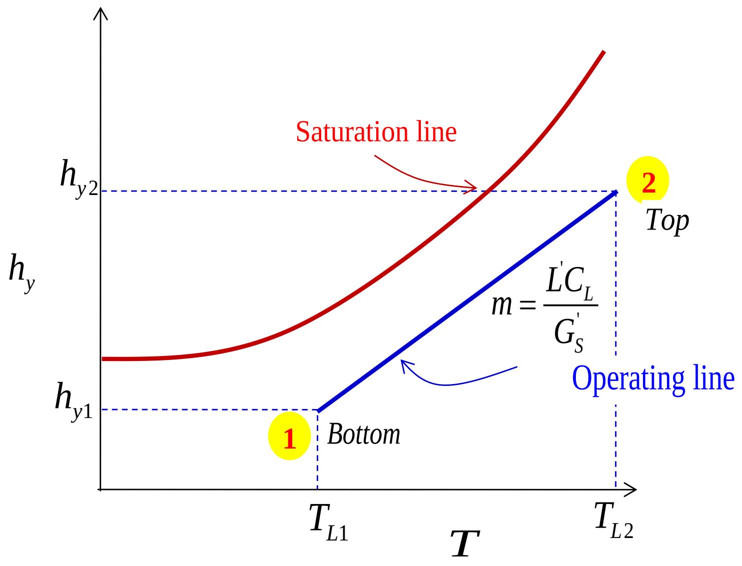


Figure 3.Characteristic operating line of the system

Figure 2 help 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.

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

Where $k_y a$ is the mass transfer coefficient of the system, and M_B is the molecular weight of the air.

3. Results

The results were obtained running the experiments with the operating conditions shown in table 1.

3.1. Effect of the ratio L/G on the cooling tower efficiency at different inlet water temperatures

Figures 4 shows the performance of the cooling tower for different values of the ratio L/G. The efficiency always decreases when L/G increases. It makes sense because the amount of liquid increases with respect to the gas which is the cool fluid. The lower the amount of gas the lower the capacity to remove heat to the liquid.As can be seen, the experiments were done at different inlet water temperatures. When this temperature decreases, the efficiency decreases. It means that the tower has a better performance when operated at higher liquid temperatures.

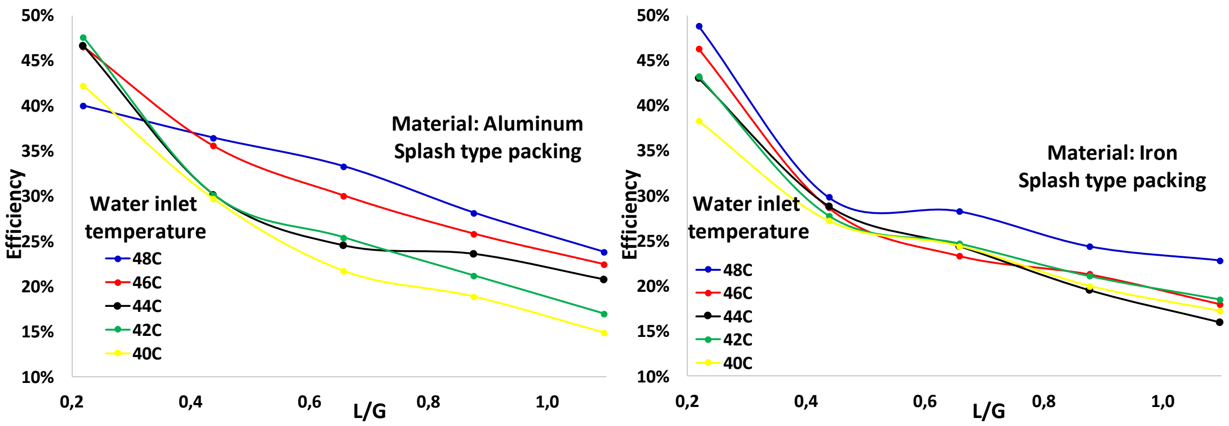


Figure 4. Behavior of the efficiency as a function of L/G at different inlet water temperatures

On the other hand, we can see that the effect of the packing materials is small. Aluminum and iron have high values of thermal conductivity, see table 3. However, results using wood and acrylic, which have small values of thermal conductivities, had the same pattern. The only difference is that at high values of inlet water temperatures when packing material is aluminum, the patter of decrease of the efficiency is linear while at low values on inlet water temperatures the trend is an exponential decay. In the case of iron as packing material, the efficiency trend is an exponential decay for all the inlet water temperatures. We can see the effect of the packing material in a better way in the next item.

3.2. Behavior of the cooling tower efficiency for different packing materials

Figures 5shows the behavior of the cooling tower efficiency for different values of the ratio L/G and, for different materials. It was used splash type packing in the column.As can be seen in figure 5 there is an effect of the packing material on the efficiency of the tower. High values of thermal conductivities results in low tower efficiencies, see the black and red line in figure 5. In general working with low thermal conductivity materials (K<0.2W/m^{o}C) increase the efficiency approximatelyfrom 4.9% to 9.3% when compared with high thermal conductivities materials (K>80.2 W/m^{o}C), operating the tower in the range of L/G from 0.22 to 1.1.

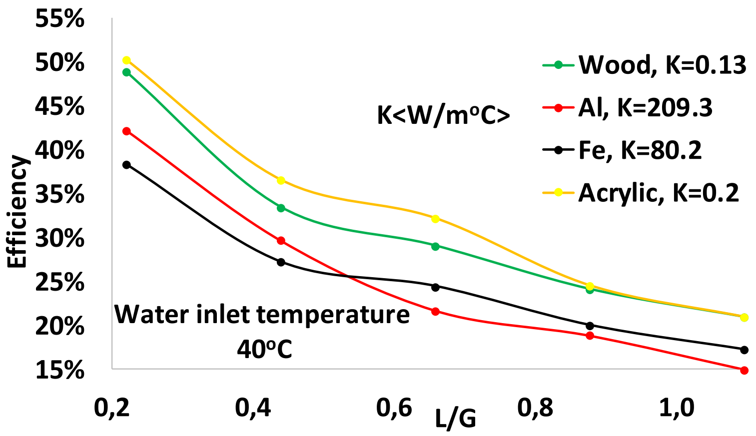


Figure 5. Behavior of the cooling tower efficiency as a function of L/G for different materials of the splash type packing.

Figures 6 shows the effect of the shape of the packing in the efficiency of the tower. In this plot, there is a comparison of the packing shown in figure 2a and 2b. The blue line corresponding to the film type packing, give a better efficiency to the cooling tower for all the values of L/G. The reason of that pattern is due to thehigh surface area of the packing shown in figure 2b, letting a better contact with the air and the water causing a better heat and mass transfer resulting in a better efficiency of the tower. The packing produces a higher difference in efficiency at low values of L/G. At high values of L/G, there is no significant effect. When L/G is 1.1,the resulting increase in efficiency using the film type packing compared to the splash type packing is around 16.6% while it increases to 47.1% when L/G decreases to 0.22.

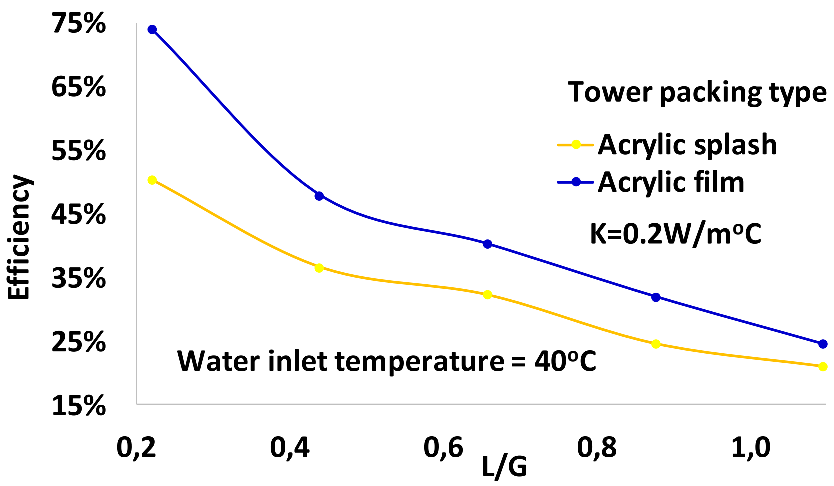


Figure 6. Behavior of the cooling tower efficiency as a function of L/G for different shapes of the acrylic type packings.

3.3. Operating line

Figures 7 shows the saturation curve of the air with operating line of the cooling tower for the following conditions, G=91034Kg(dry air)/hr.m^2, L=10093.3 Kg/hr.m^2, T_{BS1}=26°C, T_{BH1}=22°C, T_{L2}=48°C, T_{L1}=41.5°C, T_{BS2}=38°C, T_{BH2}=36.5°C.

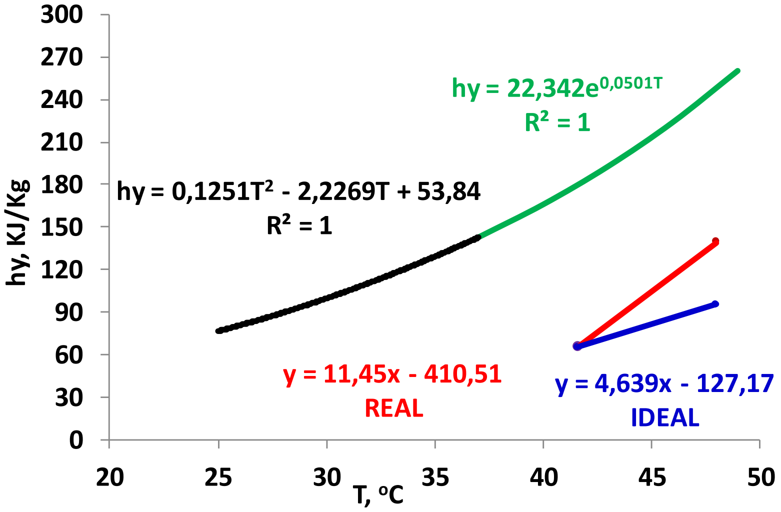


Figure 7. Operating line behavior when using acrylic film type packing in the cooling tower

As can be seen in figure 7 there are two operating lines, the red line corresponding to the real data obtained from experiments, and the blue line corresponding to the calculated data of the exit air using energy balances. As can be seen, there is a large difference between them,and it happens because it was used the Merkel equation that takes into consideration negligible the amount of water evaporated. It causes another mistake when calculating the values of the mass transfer coefficient Kya which is an important parameter when trying to optimize a real cooling tower due to it tends to depend on different factors such as the ratio L/G, the type,and shape of packing and the operating conditions. It implies that during the design of cooling tower it is necessary to use the heat of evaporated water.

4. Conclusions

In the present work, it was studied the performance of a cooling tower under different operating conditions using different types of packing.

It was found that the tower efficiency decreases when L/G increases due to the lower the mass rate of air the lower the capacity to remove heat to the liquid.

Similarly, it was found that the tower efficiency decreases when the inlet water temperature decreases. It implies that the tower has a better performance when cooling liquid at high temperatures.

High values of thermal conductivities in the packing results in low tower efficiencies. Low thermal conductivity materials (K<0.2W/m^{o}C) increase the tower efficiency around 4.9% to 9.3% when compared with high thermal conductivities materials (K>80.2 W/m^{o}C), operating the tower in the range of L/G from 0.22 to 1.1.

The use of packing with high surface area results in better efficiency in the tower. It was found that for values of L/G around 1.1 the resulting increase in the tower efficiency using the film type packing compared to the splash type packing was around 16.6% while it increases to 47.1% when L/G decreases to 0.22.

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