A STUDY ON THE UTILIZATION OF ALTERNATIVE MATERIALS AS PACKING FOR COOLING TOWERS

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Abstract. *The present work studies the behaviour of two alternative materials as packing for cooling towers: a vegetal fiber (Cocos nucifera Linnaeus) and the neck of P.E.T. bottles. In order to investigate the thermal behaviour of those materials, a prototype of a cooling tower with forced circulation in counter flow was built. The temperatures were indicated by thermocouples T, with 0,5mm diameter, by the use of a data logger system. The effect of water flow, air flow and thermal load over the packing was studied, compared to a pattern packing of trapezoidal grid of polipropylen, used for hard water. Results relating the kind of packing to the cooling capacity (ΔT) and to the approach were discussed. A program in MATLAB was developed in order to evaluate the NUT for each packing. The results indicated that alternative packings are a possible option for cooling towers.*

Keywords: *evaporative cooling, cooling towers, packing, heat and mass transfer.*

1. INTRODUCTION

Population growth and pollution of waters are indications that precisely water will be a necessary but at the same time, a rare good. The industry is a large consumer of water. This situation is established because almost all industrial processes, as well as systems of refrigeration and air conditioning, must reject heat. This rejection is processed by means of air or water. Cooling towers are equipments that use the principle of evaporative cooling for extracting heat out of the process. Those equipments achieve better results of heat transfer because their theoretical cooling limit is not the dry bulb temperature, but the wet bulb temperature, which is smaller than the temperature of the air. It is also true that, due to heat and mass transfer process, a small quantity of water evaporates (circa of 2%) but the other part returns to the industrial process, saving water and preserving the environment.

The operation of cooling towers requires that water drops fall over a large surface where air is flowing. Due to processes of heat and mass transfer (removal of sensible and latent heat of the falling water), also a part of that water evaporates and is incorporated by the air flow. The remaining water, with a lower temperature, is collected at the bottom of the tower and can be used for absorbing heat.

Kloppers & Kröger, (2003) carried out experimental studies among three types of arrangement of cooling packings in order to validate empirical correlations to evaluate the coefficient of pressure drop in cooling towers.

Naphon (2005), proceeded to an experimental study on cooling towers in order to analyse theoretical and experimental results. In this work a plastic packing in form of plates, subdivided in eight layers, was used. He came to the conclusion that the air flow influences the cooling tower outlet air flow, as well as the temperature of the cooled water flow that leaves the tower. This study also shows the increase of the pressure drop with growth of the air flow.

Elsarrag (2006) tested clay bricks as cooling pad for cooling towers, studying deterioration of materials for packing and testing correlations to predict the mass transfer coefficient. Those correlations presented a maximum error of ±10%.

Many numerical studies focuses on the performance of cooling towers in a variety of operational and atmospheric conditions. An example of this kind of study was carried out by Facão, (2004) that proceeded to a study of the operational conditions of a cooling tower of indirect cross-flow. Three cases were studied numerically using the obtained correlations. Kairouani et al, (2004) developed a mathematical model based on the principal ways of heat and mass transfer to predict the performance of cooling towers of cross-flow. Kranc (2007) utilized a numerical analysis to optimize the distribution of water through a water injection system and its influence on the performance of a cooling tower. He showed that a radial distribution brings a better performance. One of most important aspects to investigate the performance of cooling towers is their efficiency, which is directly influenced by the cooling water range. The cooling water range, by its turn, is influenced by the kind of packing, which indicates a reduction of even 40% on the cost of a cooling tower with same capacity and with materials of identical quality Wieser (2006).

Therefore, an important contribution to the study of cooling towers focused on the packing material. Alternative materials, that could lower the price of a cooling tower can be an important issue, Costa (2006) studied alternative materials that could act as packing for cooling towers.

2. ALTERNATIVE PACKING MATERIALS

Cooling towers have a packing material, the cooling pad, which offers a large superficial area to put water in contact with air, in order to maximize heat transfer. Those cooling pads present many forms and are made of many materials. They are classified in laminar and drop packings.

The packing of a cooling tower has the finality of accelerate the heat transfer by enlarging the time of contact between air and water. The packing should be built in a low cost material, with easy installation. It should also offer a weak resistance to the passage of air and maintain a uniform distribution of water and air along the life of the cooling tower. It is also important that the material presents a good resistance against deterioration.

This work proposes two alternative materials as packing for cooling towers: Necks of P.E.T. bottles (here called PET) and the coconut fiber (here called FDC). The PET is hazardous to the environment. Mainly the necks of PET are tough to recycling centers, because they are hard, resist to high pressure and are not so easy to work as the rest of the bottle. Another alternative material studied is the coconut fiber, which was chosen to act as packing for cooling towers due to the large superficial area, durability, availableness, resistance to deterioration and low cost. The fiber was utilized in form of an interlaced thread, inside a metallic support. All this was built in a way to allow the passage of the water film and air, through channels among the fiber. The Fig. 1 shows the alternative materials.

The alternative packings were tested against an industrial packing of the same volume, commonly used at the industry for troublesome waters. This cooling pad was named INDUSTRIAL and can also be seen in Fig. 1.

Figure 1. P.E.T. (PET) and coconut fiber (FDC) acting as packing for a cooling tower. They were tested against a commercial cooling pad (INDUSTRIAL).

3. EXPERIMENTAL ANALYSIS

In order to analyse the behaviour of the mentioned materials, namely the coconut fiber (FDC) and the necks of P.E.T. bottles (PET), an experimental cooling tower was built. The prototype was a counter flow tower, built in aluminum profiles in "*L*" shape and acrylic, with a water basin in brass. The system for distribution of water was composed by PVC tubes. The system counted with electrical resistances, diffusers, axial ventilator and a centrifugal pump with a by-pass to control the flow, besides a wattmeter, to control the velocity of the fan. Figure 2 shows a scheme and a general view of the prototype. For testing the cooling pad, a contention (0,48mx0,48mx0,50m) was built, where the arrangements of cooling pads were investigated, as shown in Fig. 1.

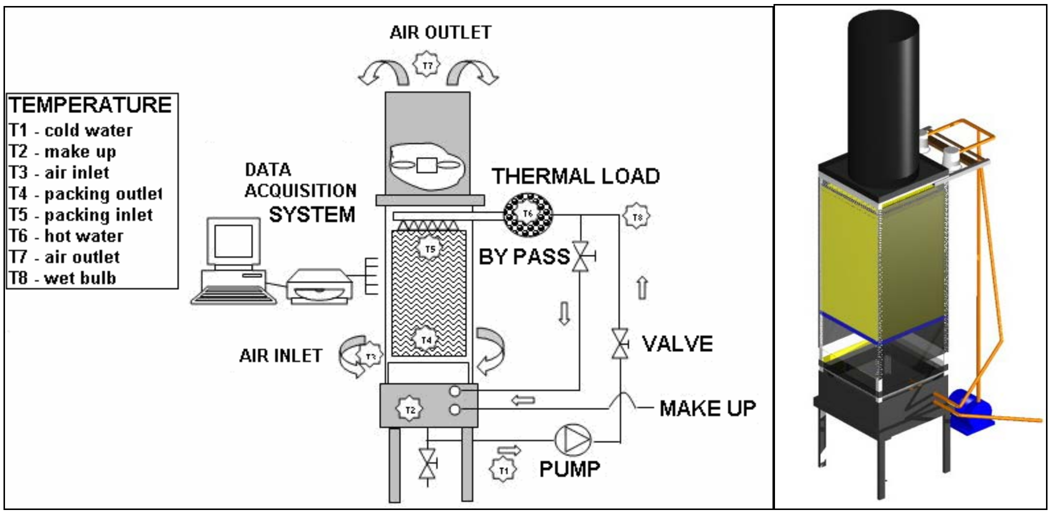

Figure 2. Scheme and general view of the experimental cooling tower.

4. NUMERICAL SIMULATION

The study of cooling towers requires the investigation of two distinct phenomena, that act merged, the heat transfer and the mass transfer. Both phenomena are important to understand and to mathematically modeling of cooling towers. The laws that rule those mentioned phenomena are Newton's Law for heat transfer through convection and Fick's Law of Diffusion for mass transfer. Equations 1 and 2 define each law, respectively, where Q is the heat flow (W), h_c is the heat transfer coefficient through convection (W/m^{2}K), A is the area (m^2), T_s is the temperature close to the wet surface (K), T_∞ is the air temperature far from the wet surface (K), $\dot{m}_v$ is the rate of mass transfer (kg/s). h_d is the coefficient of mass transfer through convection (W/m^{2}K), ρ_s is the density of the air close to the wet surface (kg/m^3), ρ_∞ is the density of the air far from the wet surface (kg/m^3):

$$Q = h_c A(T_s - T_\infty) \tag{1}$$

$$\dot{m}_v = h_d A(\rho_s - \rho_\infty) \tag{2}$$

A very common procedure when both phenomena act together is try to construct analogies between them. This is proved in various practical situations for flows of fluids for different geometries, as well as for turbulent and laminar flows. Therefore, the mass transfer coefficient can be evaluated through analogy with the correlations to evaluation of the heat transfer coefficient for convection. In this way, a non-dimensional number, very useful to analysis including heat and mass transfer, the Lewis' number, Le, is given as follows,

$$\frac{h_d}{h_c C_p \rho} = \left(\frac{Sc}{\Pr}\right)^{2/3} = \left(\frac{\alpha}{D}\right)^{2/3} = Le^{2/3} \tag{3}$$

By analysis of Eq. 3, it is clear that the Lewis' number is the relation between Schmidt's (Sc) and Prandtl's (Pr) numbers, which also is the relation between the thermal diffusivity (α) and the mass diffusivity (D), with C_p as the specific heat (kJ/kgK). For this relation, Lewis found the value of 0,865 for humid air. Based on this relation Lewis found another group of non-dimensional, that would be called as Lewis' factor, *Lef*:

$$Lef = \frac{h_c}{h_d C_p \rho} = (0.86)^{2/3} = 0.90 \cong 1 \tag{4}$$

Acknowledging this result is possible to evaluate the mass transfer coefficient through the convection heat transfer coefficient. According to Kloppers & Kroger (2005), for simulations of cooling towers, while Merkel utilized the unitary value for the Lewis' factor, Poppe & Rogener utilized the equation of Bosnjakovic, which expresses Lewis' factor in a even more restrict evaluation. When humid air is evaluated, the removal or addition of vapour of water is unavoidable. With such kind of manipulation amounts of heat can be removed or added, in form of sensible or latent heat. In conformity to Trovati (2006), the sensible heat (convection heat transfer) occurs due to the temperature difference between air and water. This kind of heat is responsible for 20 a 30% of the total heat. The latent heat, owed to the mass transfer, occurs due to difference in concentration between the wetted surface and the circulating air. This amount of heat is responsible for 70 to 80% of the total heat. Therefore, the total heat transferred (Q) in an evaporative system is the sum of the parcels of transfer in form of sensible (Q_s) and latent heat (Q_L), indicated by Eq. 5:

$$\delta Q = \delta Q_S + \delta Q_L \tag{5}$$

By the modeling of cooling towers, some simplifications are used to facilitate the evaluation, as Lewis' factor equal to unity, constant water flow (that means, no lost for evaporation) and the air is saturated of water vapour, characterized only by the enthalpy. Under those simplifications Eq. 5 can be evaluated by Eq. 6, which is known as Enthalpy Potential.

$$\delta Q = \frac{h_c dA}{c_{p_u}}(h_i - h_{ar}) \tag{6}$$

This equation allows the determination of heat and mass transfer in a cooling tower and the direction that heat transfer is happening, e.g. from water to air or from air to water. With the help of this equation, is possible to utilize the NUT method (Number of Unities of Transfer), which is basically the method utilized by ASHRAE, given by Eq. 7:

$$NUT = m_{ag} \int_{T_1}^{T_2} \frac{c_{p_{ag}} dT}{(h_i - h_{ar})} \tag{7}$$

Through the method of numerical integration of Simpson the NUT is evaluated. Through the difference of the middle values for the enthalpy of the air and the wetted surface for each section, the state of the air through the cooling tower is evaluated. Eventually, to finish the evaluation of the conditions at the outlet of the cooling tower, the temperature of water at the exit of the tower need to be evaluated. This method is not a direct method, as the evaluation of NUT or the evaluation of the air conditions. After the NUT is evaluated, through the experimental data for the inlet and outlet of the tower, other than the experimental conditions can be determined. Those procedures should predict the inlet and outlet temperature for the water. An initial value for the outlet temperature is set, as well a usual value for the wet bulb temperature (air). The NUT is then evaluated. If the evaluated value is higher (or lesser), the temperature of the water at the outlet of the tower is increased (or diminished). This procedure is repeated until the convergence criterion is achieved.

5. RESULTS AND DISCUSSIONS

Figure 3, 4 and 5 show experimental results for the investigated cooling pads. The industrial packing presented the better efficiency. This emphasizes the importance of the lowest possible approach, because the approach influences the global analysis of the packing. The cooling pads of P.E.T. (PET) and coconut fiber (FDC) presented efficiencies lower than the industrial, but they were indeed very close to a packing that is widely used in the industry. However, the packing can not only be chosen simply by the cooling.

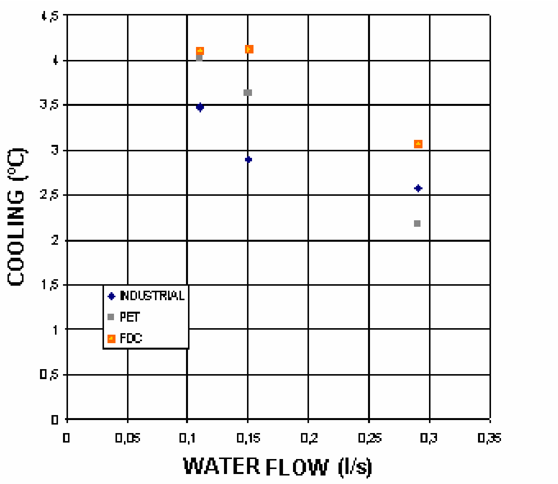

Figure 3. Cooling versus water flow (l/s) – Influence of water flow for each cooling pad, for a constant thermal load of 6600W and a constant air of 0.49 m³/s.

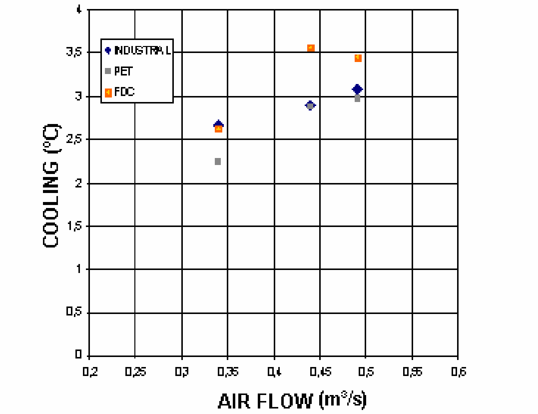

Figure 4. Cooling versus Air flow (m^3/s) - Influence of air flow for each cooling pad, for a constant thermal load of 6600W and a constant water flow of 0.29 l/s.

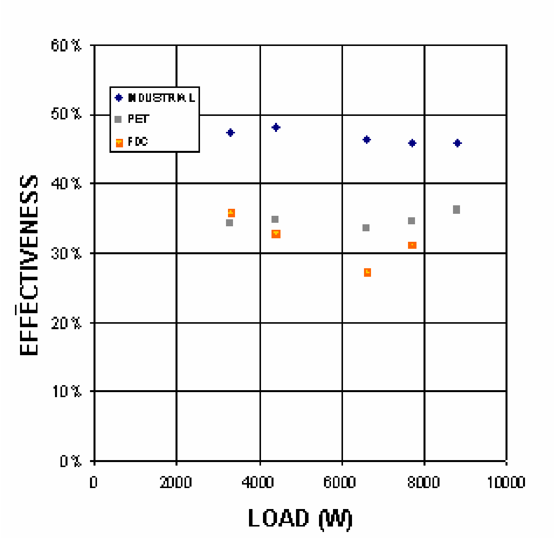

Figure 5. Effectiveness versus Thermal Load (W) - Influence of thermal load for each cooling pad, for a constant air flow of 0.49m³/s and a constant water flow of 0.29 l/s.

The value of NUT through the tower is almost constant for a fixed value of water flow and air flow. The relation between those two flows is known as L/G. Figure 6 indicates the value of NUT versus Thermal Load for three different values of L/G. It exists an almost linear behaviour of the NUT for each relation L/G, where the medium value was evaluated with uncertainness less than 0,5%. There is a clear dependence between the NUT and the relation L/G. When L/G increases, the NUT diminishes and vice versa.

The NUT of the INDUSTRIAL pad is the best, followed by the NUT of FDC and the NUT of PET. The same tendency was observed for the effectiveness. Those results agree with the experimental results. If the NUT increases, the temperature of the water is more close to the wet bulb temperature (small approach) and the packing has a better behaviour for different atmospheric situations.

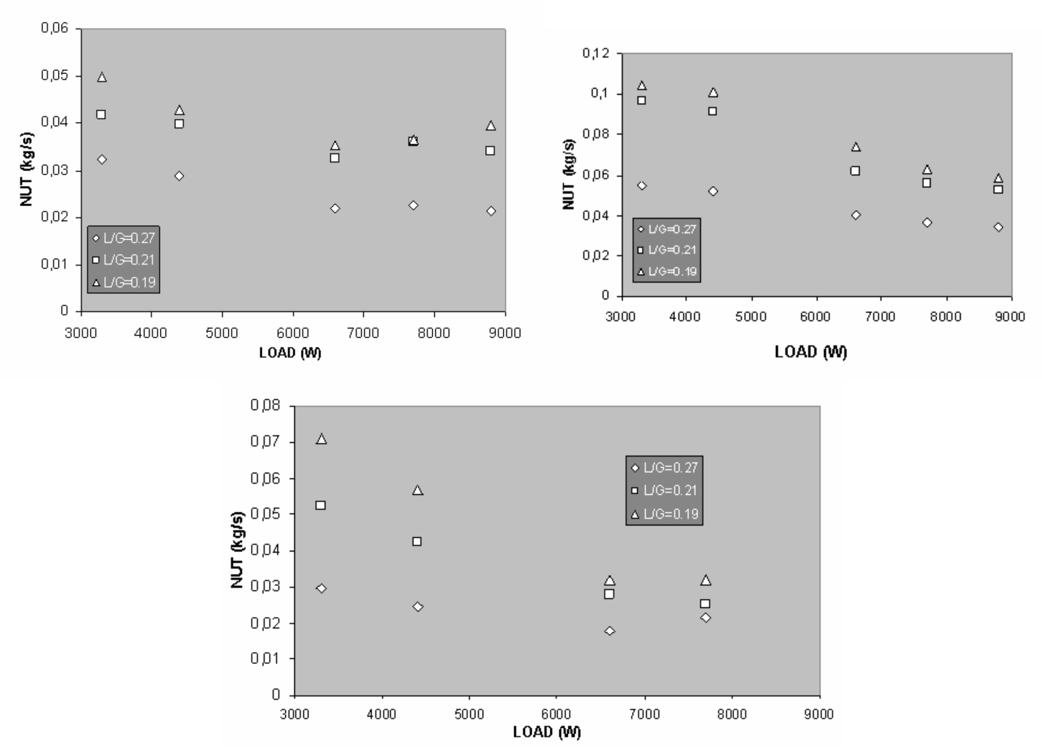

Figure. 6: Comparison among numerical results for NUT: PET, INDUSTRIAL and FDC, respectively.

The numerical results were tested for different conditions inside the experimental values, e.g. variation of the Cooling, Approach and Effectiveness with the variation of the temperature of water at the inlet of the cooling tower, for a constant relation L/G. The results are in good agreement, as shown by Fig. 7.

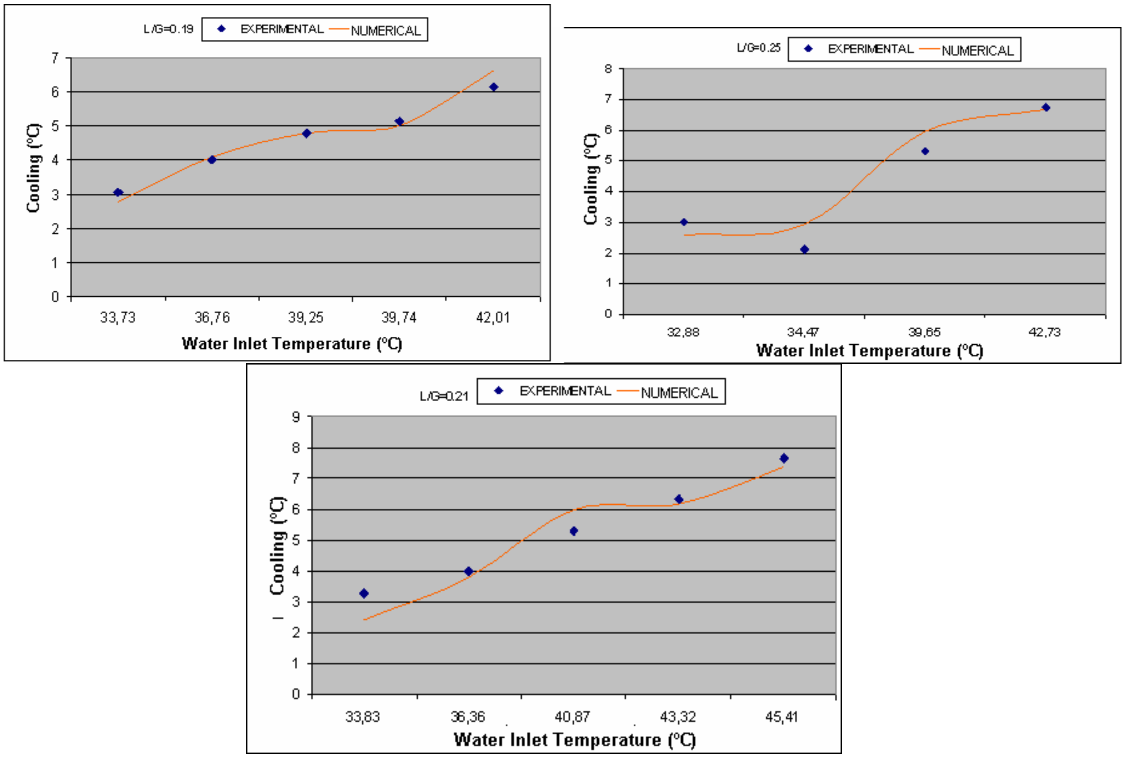

Figure 7. Comparison among experimental and numerical results for PET (L/G 0.19), FDC (L/G 0.25) and INDUSTRIAL (L/G 0.21), respectively.

6. CONCLUSIONS

The results allow some conclusions about the influence of the air flow, water flow and thermal load of the system. The air flow has a direct influence over the temperatures in the tower, modifying consequently the approach, the cooling range and the effectiveness. It is also verified that large superficial areas implies in obstruction of the passage of the air flow, reducing the analysed parameters, namely the effectiveness, the cooling and the approach. Due to this, that should exists a compromise in enlarging the contact area and at the same time offering good conditions for the air flow through the cooling pad.

The distribution of water over the cooling also has a remarkable influence in the performance of the system. It was observed that, if the water flow increases, the range of cooling decreases, as well as the approach. The effect is the reduction of effectiveness. The influence of the water flow was stronger for packings with large contact area, as for the coconut pad. This effect was very smooth for the investigated industrial packing.

The numerical simulation allowed the prediction of the thermal behaviour of the tower for many cooling pads, as well as for different psicrometric conditions, showing the agreement among the experimental results. This allows the study of the thermal behaviour of each packing without necessity of another set of experiments. It was also observed that the rate of evaporation has a close dependence of the relative humidity. This behaviour was observed for all studied cooling pads.

The results of this study indicate that P.E.T. and coconut fiber packing are promising as cooling pads for cooling towers. The alternative packings, although with arrangements not optimized as the industrial pad, presented results that were not largely different as the commercial unity. Added to this, economical and environment reasons stresses the reasons for investing in those packings. However, the results cleared showed that a more accurate study of the arrangement is necessary. After the studies for optimization of the arrangements, those materials can surely be an alternative as packing for cooling towers.

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