COB09-2531 - ANALYSIS ON THE UTILIZATION OF P.E. T. BOTTLES AS PACKING FOR COOLING TOWERS.

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Abstract. *In some industrial processes, as well as in air conditioning processes, it is necessary to cool down equipments that generate heat during his operation. Usually, the fluid utilized to dissipate that generated heat is water, due to its physical characteristics (high heat capacity, low viscosity, high thermal conductivity and high density). It is also non-toxic, it presents a good availability and low cost. A cooling tower to refrigerate water is an equipment that utilizes processes of evaporation and heat transfer to cooling water, which is sprinkled over a packing that enlarges the contact area between air and water. Commonly, the materials used as packing for cooling towers are wooden laths, plastic and fiberglass. The cooling packing influences the final price of a cooling tower and can be responsible for even 40% of the total cost of a cooling tower. In this work, the main focus is given to PET bottles, with the following configurations: two arrangement for PET threads and two arrangements for PET neck bottles. The results were compared by testing two commercial cooling packing: a vertical offset corrugated packing and a trapezoidal grid packing. A prototype of a counter flow cooling tower was built for the experimental measurements. Some effects over the efficiency of the cooling tower were analyzed: temperature rising of the inlet water, rising in air flow and water flow. The results indicated that the tested cooling pads are suitable to be used as packing for cooling towers. Using the software EES (Engineering Equation Solver) a numerical simulation was carried out, showing good agreement with the experimental results.*

Keywords: *Cooling tower, PET neck bottles, heat and mass transfer, cooling pads, psicrometry.*

1. INTRODUCTION

Cooling towers were introduced as direct heat exchangers to several industrial processes involving heat transfer, as electric power generation systems, chemical and petrochemical industries or processes of refrigeration and air conditioning.

Some studies on the analysis of cooling towers were carried out with different points of view. Kloppers & Kroger (2003) proposed a new empirical equation, where the coefficient of pressure drop through the packing of a cooling tower is determined by measuring the pressure acting on a water droplet falling down through the packing.

Facão (2004) tested a small indirect contact cooling tower and determined the heat and mass transfer coefficients experimentally, discussing the effects of air humidity. The mass transfer coefficient was correlated with the air flow, while the heat transfer coefficient was linked to the pulverized water flow. It was verified that the actual correlations to evaluate the heat and mass coefficients offers lower values than those used for large industrial cooling towers of indirect contact.

Naphon (2005) investigated experimental and theoretical results of heat transfer in an experimental cooling tower. He concluded that the outlet air flow temperature tends to diminish with the increase of the air flow. The outlet water temperature is reduced with the increase of the air flow. The reduction of the water temperature due to the increase of the air flow results in an increase of the heat transfer.

Gao et al (2007) carried out measurements over the heat transfer performance in a cooling tower in counterflow with cross wind. According to the experimental results, it was verified that the variation of the temperature difference of the circulating water (ΔT) and the cooling efficiency (η) are influenced by the cross wind. Both can diminish 6% and 5%, respectively.

Muangnoi et al (2008) analyzed the influence of the environmental temperature and humidity over the performance of a cooling tower in counterflow according to the second law of the thermodynamics, through an exergetic analysis. First of all, the water and air flow properties through the tower were predicted and validated by an experiment. Then, an exergetic analysis was developed to investigate the cooling performance of the tower with different conditions of the admitted air (distinct relative humidity and dry bulb temperature) while the water flow remained constant. Muangnoi et al (2008) offered an explanation to the performance of cooling towers and leaves clear indications for their optimization.

Some authors also have been investigating the efficiency of alternative materials as packing for cooling towers, as Tinôco et al (2001), who compared the efficiency of some porous materials as expanded clay pellets, sawdust, vegetal fibre and charcoal. Based on this investigation is possible to indicate that, among the four mentioned materials, expanded clay pellets and charcoal are the best materials for evaporative cooling pads.

Al-Sulaiman (2002) investigated the performance of three vegetal fibre from Saudi Arabia, in order to be used in evaporative cooling systems: palm fiber (stem); jute and luffa, using a commercial evaporative packing as reference for the tests. The performance criteria included cooling performance and material degradation, as salt deposition and biodegradation. The results showed that the middle cooling efficiency of the fibre was: jute (62,1%); luffa (55,1%); commercial packing (49,9%) and palm (38,9%).

Barros (2005) projected and built a tunnel to investigate the cooling performance of vegetal fibres, studying sisal and coconut fiber acting as evaporative pad.

Elssarag (2006) carried out several tests using an induction cooling tower utilizing clay bricks as cooling packing. It was verified that the factors that affect the heat and mass transfer are: ratio water flow/ air flow, water inlet temperature and air inlet enthalpy.

Araújo (2006) investigated experimentally the behavior of local vegetal fibres as cooling packing for evaporative systems. Vegetal sponge (*Luffa Cylindrica*), sisal (*Agave Sisalana Perrine, Amarilidaceae*) and coconut fibre (Cocos Nucifera Linnaeus) were studied. As reference, a widely used evaporative cooling packing based on kraft paper was used. A tunnel was projected and built for tests. The experimental results indicated that sisal is so efficient as luffa. Their efficiency were 44,93% and 44,72%, respectively. The coconut fibre was a promising material for a cooling packing, with an efficiency of 52,24%, while the commercial packing presented an efficiency of 65,9%.

Costa (2006) studied the behavior of alternative materials as cooling pad for cooling towers. The following materials were studied: vegetal sponge (Luffa Cylindrica), coconut fiber (Cocos nucifera Linnaeus), plastic hair rollers and necks of PET bottles. In order to investigate the performance of those materials, an experimental counterflow cooling tower was projected and built. Some effects due to the variation of water flow, air flow and thermal load on the packing were studied, in comparison to a standard packing, with trapezoidal grid, built in polipropylen, commonly used at industries that work with heavy waters. The results were presented linking the kind of packing to the cooling range (ΔT) and *approach* of the cooling tower. The commercial packing indeed showed better performance, with efficiency of 46,40%, followed by the packing of plastic hair rollers, with 40,30%, PET neck bottles 33,61%, coconut fiber (27,8%) and lately the luffa packing, with 20,97%. This conditions were achieved for a water flow of 0,11 l/s and an air flow of 0, 49m³/s.

This article continues the research line that investigates alternative materials to evaporative systems, followed by the last three mentioned authors. The emphasis of this work is given on the evaluation of threads and necks of PET bottles. The threads and necks of PET bottles were investigated for two configurations each. The obtained data were compared to the data obtained for two different kinds of commercial packing for cooling towers of the same manufacturer. The PET bottle was chosen as material for cooling packing because it is resistant to the operational temperature of cooling towers, has a low cost and it is very easy to set a new configuration of the packing, allowing several configurations in order to maintain a uniform distribution of water and air in the cooling tower. The neck bottles have a profile that increases the contact between water and air, leading to better conditions of heat and mass transfer. In this way, the cooling packing of a cooling tower would be ecologically correct, because it would utilize a recycled material, that pollutes the environment.

2. METODOLOGY

2.1 Experimental Metodology

In order to carry out the necessary experimental tests, a prototype of a cooling tower was used. The prototype presented by Costa (2006), based on a counterflow cooling tower, was improved. The scheme of the prototype with indication of the points for measurement is shown by figure 2.1.

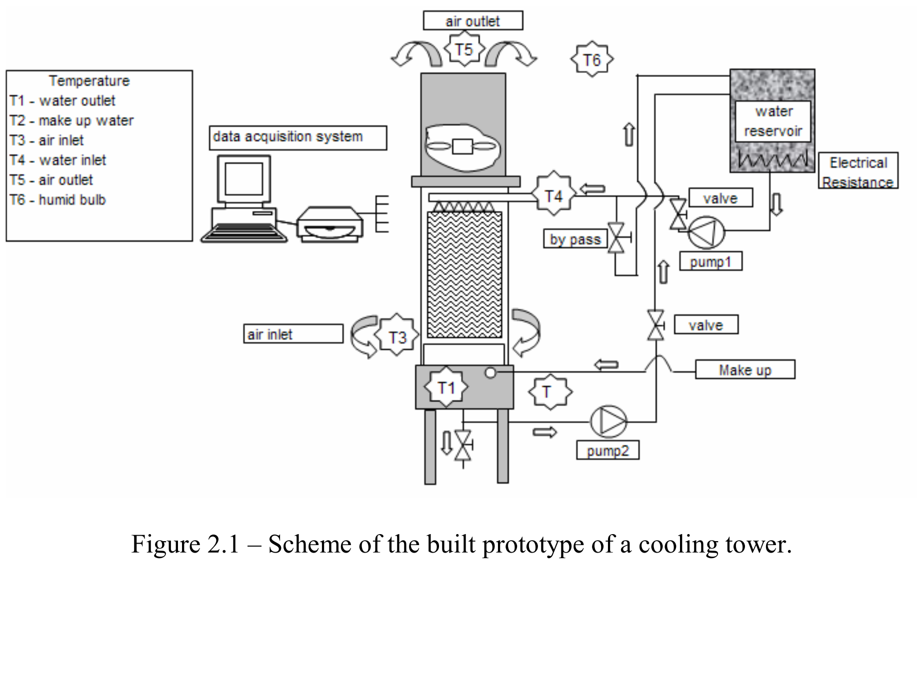

Figure 2.1 – Scheme of the built prototype of a cooling tower.

As cooling packing, PET material was utilized, as shown by figure 2.2 to 2.7. In the figure 2.2 the arrangement utilized PET crossed threads. Figure 2.3 shows an other kind of arrangement, were the test section was filled with loosed PET threads in a randomized configuration. Figure 2.4 shows an arrangement with neck bottles in a crossed disposition. Figure 2.5 shows an other arrangement with neck bottles in crossed rows.

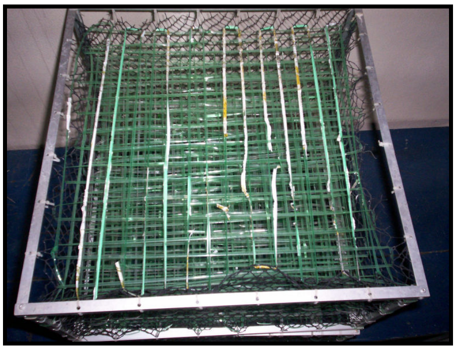

Figure 2.2 – Crossed PET threads (thread 1) .

Figure 2.3 - PET Loose threads (thread 2).

Figure 2.4 – Crossed neck bottles (neck 1).

Figure 2.5 – Neck bottles in crossed rows (neck 2).

In order to compare the results, two different kinds of commercial packing were utilized. The first one presented a vertical corrugation and the other was built in a trapezoidal grid, as shown by figure 2.6 and 2.7, respectively. Both packing are commonly used by industries.

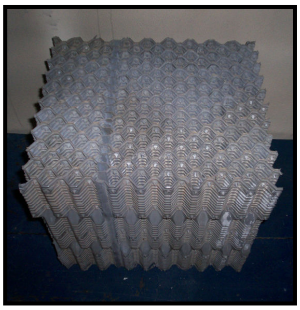

Figure 2.6- Industrial packing with vertical corrugation (industrial 1).

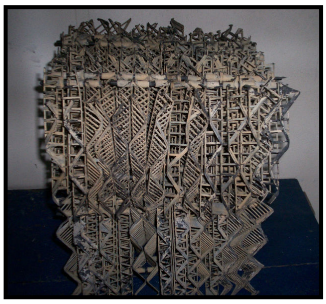

Figure 2.7 - Industrial packing with trapezoidal grid (industrial 2).

The packing made of crossed PET threads was named “thread 1”. The packing made of loosed PET thread was named “thread 2”, the packing made of crossed necks of PET bottle was called “neck 1”. The packing made of PET in crossed rows was called “neck 2”. The industrial packing with trapezoidal grid was named “industrial 1” and the industrial packing with vertical corrugation was named “industrial 2”.

The temperature were measured in significant points of the cooling tower prototype, as shown by figure 2.1, as well as air flow and water flow, as indicated by figure 2.1. Analyzing the collected data, it was possible to evaluate the cooling range, the approach, the effectivity and the ratio water flow divided by air flow (L/G) of the cooling tower. The water inlet temperature were taken as (32, 34 e 36°C). The water flow were chosen as (0,19 0,22 e 0,29)l/s and the air flow of (0,34 0,44 e 0,49m^3/s). Each packing was tested with 27 different conditions, by variation of the mentioned conditions. The values for the water inlet temperature were chosen because they represent current values of real cooling towers working for air conditioning systems. In order to simulate the different values of temperature, an electrical hot-water heater of 4500W was used. The resistance was ruled by an electronic digital controller.

The temperature of the air at the inlet and outlet of the prototype, as well as the dry bulb and humid bulb temperature were measured by thermocouples and collected by a data acquisition system based on LABVIEW. The approach and the cooling range were evaluated directly by the LABVIEW.

2.2 Numerical Simulation: EES

The Mep (or NUT) is evaluated to each packing taking experimental data as basis. After the NUT is known, different situations are simulated to predict the operational conditions of the cooling tower, as for example, the inlet and outlet water temperature. The evaluation utilizes an iterative process using the software Engineering Equation Solver (EES). A good initial value for the water temperature is to admit that the outlet water temperature is equivalent to the humid bulb temperature of the inlet air. With this value, the procedure is executed to evaluate the corresponding NUT. If the evaluated NUT is greater or lesser, the value of the water temperature at the outlet is increased or diminished. New evaluations are carried out until the set approximation is achieved. The equation used to calculate the NUT is given by equation 1:

$$NUT = \dot{m}_{ag} \int_{T_1}^{T_2} \frac{c_{p_{ag}} \, dT}{(h_i - h_{ar})} \quad \text{(Eq. 1)}$$

where $\dot{m}_{ag}$ is the water flow (kg/s), c_{pag} is the specific heat of water (kJ/kgK), h_{ar} is the specific entalphy of dry air (kJ/kg) and h_i is the entalphy of saturated air at the water temperature (ºC).

3. DISCUSSION OF RESULTS

3.1 Variation of the water inlet temperature

Figure 3.1 shows the behavior of the Cooling Range (°C) as a function of the water temperature at the entrance of the tower. It is observed that the results presented by different kinds of packing were close to each other. The experimented cooling packing made of crossed PET threads (thread 1) presented the best results for this kind of simulation, closed followed by loosed PET thread (tread 2), neck bottles in crossed rows (neck 2), crossed neck bottle (neck 1), industrial with trapezoidal grid (industrial 1) and industrial with vertical corrugation (industrial 2). The cooling packing made of neck bottles presented a cooling range close to the best results for the industrial case (industrial 1). The commercial pad with vertical corrugation presented the poorest cooling range, probably because it needs a uniform water spray through the whole packing. This condition was unfortunately not achieved with the utilized spray nozzles.

However, it must be pointed out that the difference among the best and worse results can be found in a range of only one (1) Celsius degree. It should also be observed that the cooling range is influenced by the temperature of the water inlet temperature. An increase in the temperature of the water at the entrance of the tower also increases the temperature difference between the air and water at the entrance of the tower, generating an improvement of the cooling tower performance.

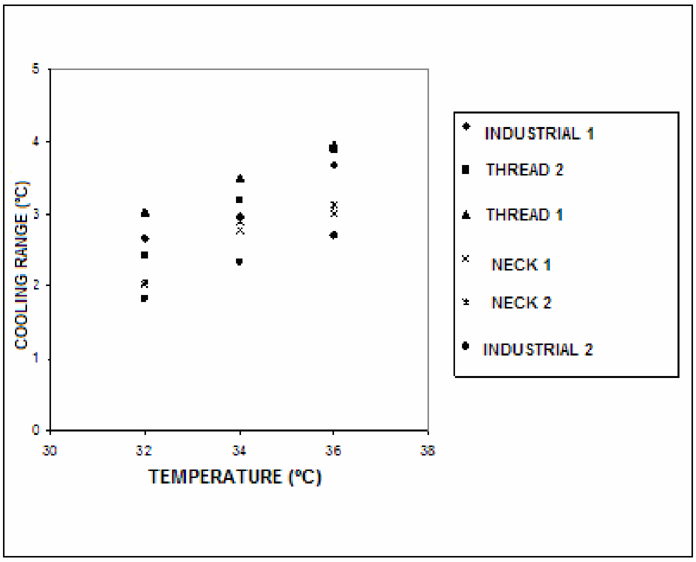

Figure 3.1 - Cooling Range (ºC) versus Temperature (ºC) – Comparison among different packings with a constant air flow of 0.49m³/s and a constant water flow of 0.22 l/s.

Figure 3.2 shows the behavior of the approach versus water inlet temperature. It is observed that the results are very closed to all tested packing. Among the tested packing, the industrial packing with vertical corrugation (industrial 1) presented the highest approach, followed by the crossed neck (neck 1). A larger approach means a poorest cooling performance, because the approach indicates the capacity of the cooling tower to obtain temperatures near the humid bulb temperature, which is the maximum limit for a cooling tower. The packing made of crossed threads (thread 1) and the packing with loosed threads (thread 2) presented the best results, indicating low values for the approach. It must be pointed out that the results for approach can be found in a narrow range of 0,5^{o}C for lowest values of water inlet temperature at the cooling tower and 2^{o}C, for highest water inlet temperature.

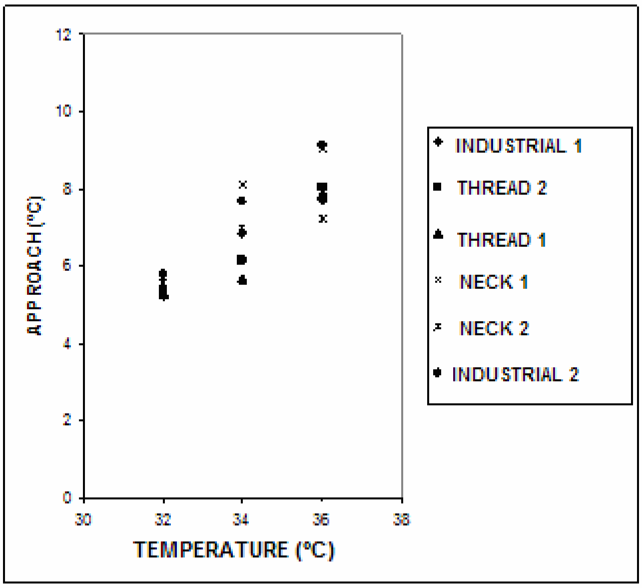

Figure 3.2 - Approach (°C) versus temperature (°C) – Comparison among packings, for an air flow of 0.49 m³/s and a water flow of 0.22 l/s.

Figure 3.3 shows the efficiency versus water inlet temperature. It can be noticed that the packing named thread 1 presented the best efficiency, close followed by the loosed thread (thread 2), for values of air flow of 0,49 m³/s and a water flow of 0.22 l/s. This stresses the importance of low values for the approach, because it influences the global analysis of the packing. The packing named neck 2 (neck bottle in crossed rows) exhibited an efficiency close to the industrial 1 (commercial packing wit vertical corrugation). All efficiencies can be found close to each other, in a range of 15%.

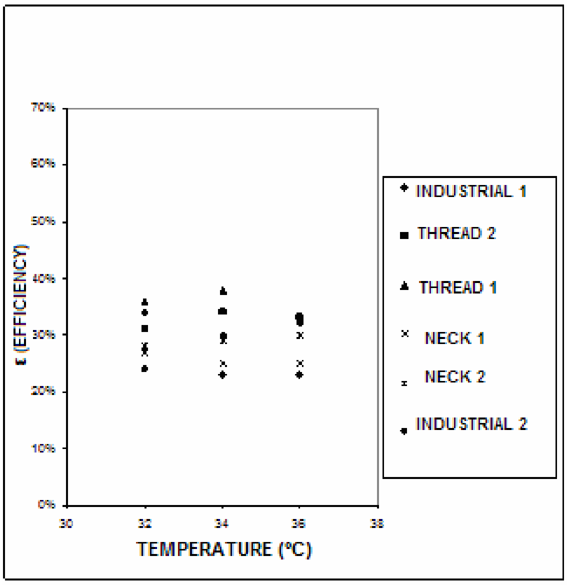

Figure 3.3 - Efficiency versus temperature (ºC) – Comparison among packings, for an air flow of 0.49 m³/s and a water flow of 0.22 l/s.

3.2 Air flow variation

Figure 3.4 shows the Cooling Range versus air flow for all tested packings. The results confirm the proportionality between the increase in the cooling performance with an increase of the air flow. It is also verified that the commercial packing with vertical corrugation offers more obstruction to the passage of air, what leads to a low performance. The results can be found in a range of 1,5 ^{o}C. The same effects were verified using other chosen values of water inlet temperature and water flow.

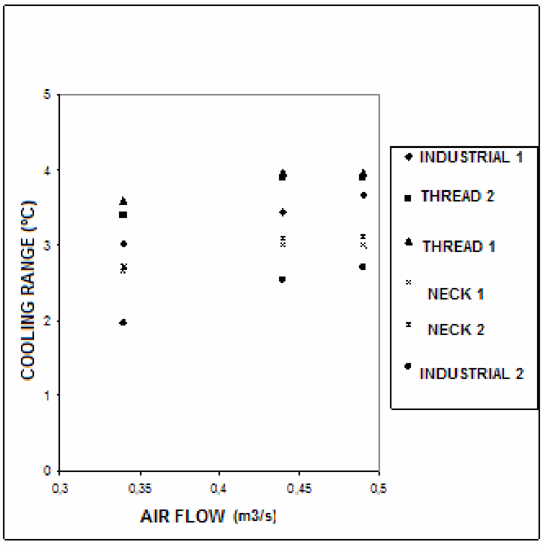

Figure 3.4 - Cooling Range versus air flow (m^3/s) – Effect of air flow over the cooling packing performance, for water inlet temperature of 36ºC and water flow of 0.22 l/s.

3.3 Variation of water flow

Figure 3.5 shows the cooling range (°C) as function of the water flow. Contrarily to the increase of the air flow, an increase in the water flow caused a reduction of the cooling tower performance. This phenomenon can be explained by relating an increase in the water flow with an increase of the thermal load of the system, for a constant air flow, what caused a reduction in the contact time between water and air. This was verified for all measurements using the chosen water temperature and water flow.

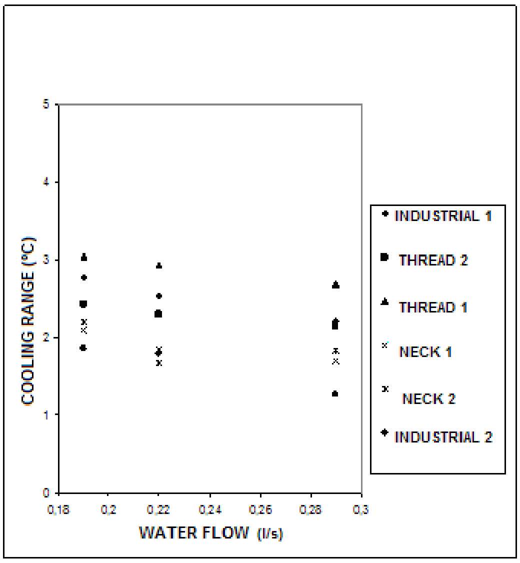

Figure 3.5 - Cooling range (°C) versus water flow (l/s) - Effect of the variation of water flow, for temperature of 32ºC and air flow of 0,44 m³/s.

3.4 Numerical Simulation

The program developed using EES is utilized to predict the thermal behavior of a cooling tower in counter flow, with variation of the meteorological conditions.

3.4.1 Evaluation of the NUT for each packing

The value of NUT through the cooling tower is practically constant for a fixed value of water flow and air flow. The ratio between these two quantities is known as L/G.

Figure 3.6 compares the NUT for the investigated cooling packing, for L/G = 0,38. The best values for NUT were achieved for the thread 2, thread 1, industrial1, neck 2, neck 1 and industrial 2. This behavior was presented experimentally, for the efficiency data, as showed previously by figure 3.3. This shows an agreement with the experimental results. It is known that high values of NUT lead to a better proximity of the humid bulb temperature. This also means a lower approach, what conducts to a better performance of the packing for different atmospheric conditions.

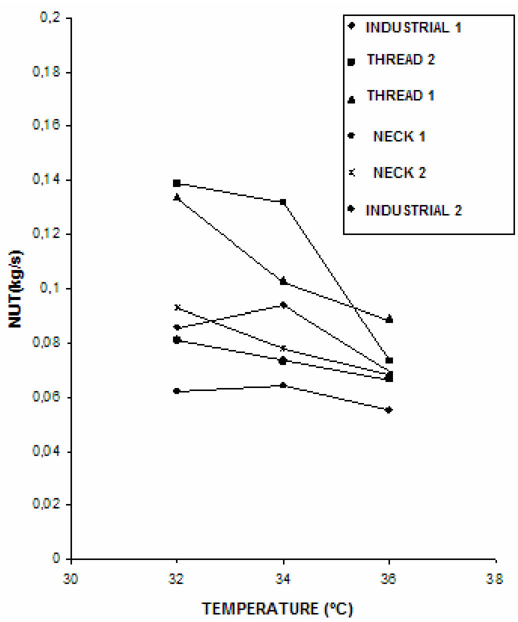

Figure 3.6 - Numerical evaluation for NUT, for L/G = 0,38.

4. CONCLUSIONS

The experimental results showed that the water inlet temperature at the cooling tower influenced all measurements. If this temperature increases, the cooling range also increases as well as the approach. The efficiency does not show such linear behavior.

It was verified that the air flow influences directly all temperatures in the cooling tower. It was also verified that large superficial areas implies to an obstruction of the air flow, reducing the parameters analyzed in this study, namely, efficiency, cooling range and approach. However, the contact area of the packing should be enlarged, but at the same time, it should offer good conditions for the air flow.

The distribution of water over the packing also influences the performance of the system. It was observed that, for large values of water flow, the cooling range becomes lower and the approach increases, causing a reduction in the efficiency.

The results obtained in this work indicate that PET bottles have an enormous potential as cooling packing for cooling towers, presenting operational conditions close or even better than the commercial cooling packing used as reference. This material has a potential to be a viable alternative as packing for cooling towers.

It was also shown, that the neck bottles also have an excellent potential to be used as packing for cooling towers, but they need an optimized arrangement.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Al – Sulaiman, F. , 2002 , "Evaluation of the Performance of Local Fibers in Evaporative Cooling", Energy Conversion and Management ,Vol. 43,pp. 2267–2273.

Araújo, S.D.O., 2006, "Análise Do Desempenho Térmico De Fibras Vegetais No Resfriamento Evaporativo". Dissertação de Mestrado – Programa de Pós-Graduação em Engenharia Mecânica – UFPE.

Barros, R. R.,2005, "Bancada Experimental para teste de enchimentos usados em resfriadores evaporativos". Dissertação de Mestrado – Programa de Pós-Graduação em Engenharia Mecânica – UFPE.

Costa, J.A.P.D., 2006, "Utilização de Materiais Alternativos como Enchimento de Torres de Resfriamento". Dissertação de Mestrado – Programa de Pós-Graduação em Engenharia Mecânica – UFPE.

Elsarrag, E., 2006, "Experimental Study and Predictions of an Induced Draft Ceramic Tile Packing Cooling Tower", Energy Conversion and Management, Vol. 47, pp. 2034-2043.

Facão, J.M., 2004, "Heat and Mass Transfer Correlations for the Design of Small Indirect Contact Cooling Towers". Applied Thermal Engineering, Vol 24, pp. 1969 – 1978.

Gao M., Sun F., Wang K., Shi Y., Zhao Y., 2007, "Experimental research of heat transfer performance on natural draft counter flow wet cooling tower under cross-wind conditions", International Journal of Thermal Sciences, Vol. 47, pp. 935-941.

Kloppers, J.C., Kröger, D.G., 2003, "Loss Coefficient Correlation for Wet-Cooling Tower Fills", Applied Thermal Engineering ,Vol. 23, pp. 2201–2211.

Muangnoi T., Asvapoositkul W., Wongwises S., 2008, "Effects of inlet relative humidity and inlet temperature on the performance of counterflow wet cooling tower based on exergy analysis", Energy Conversion and Management, Vol. 49, pp. 2495-2800.

Naphon, P., 2005, "Study on the heat transfer characteristics of an evaporative cooling tower", International Communications in Heat and Mass Transfer, Vol. 32, pp. 1066–1074.

Tinoco, I. F. F., Figueiredo, J. L. A., Santos, R. C., Paulo, M. O., Vigoderis, R. B., Pugliesi, N. L., 2002, "Avaliação de materiais alternativos utilizados na confecção de placas porosas para sistemas de resfriamento adiabático evaporativo", Revista Brasileira de Engenharia Agrícola e Ambiental, Vol.6, n.1, pp.147-150.

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