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INVESTIGATION OF THE PERFORMANCE OF AN ATMOSPHERIC COOLING TOWER USING FRESH AND SALTED WATER

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Abstract: *Cooling towers are extensively used to evacuate large quantities of heat at modest temperatures through a change of phase of the flowing cooling fluid. Based on this classical principle, the present study investigates the influence of salty water on the heat exchange produced. For that purpose, experiments are carried out using fresh and salty water. Furthermore, a comparison with the results produced through an approach involving the solution of energy equation involving the flow of air on an evaporating film of fluid. The detailed results show a preponderance of fresh water over the salty.*

Key Words: *Cooling, Tower, Reynolds, Water, Atmospheric*

I. INTRODUCTION

The continued operation of any viable installation requires a continuous and efficient cooling of its various components that occurs in most cases through the movement of a fluid. When great heat fluxes are exchanged, an important amount of fluid is required. Cooling towers are generally used to evacuate large quantities of heat with often-modest temperatures. This is achieved through the change of phase taking place during the heat exchange without walls between two fluids in contact.

The application of the phenomenon of heat and mass transport taking place in cooling towers is experiencing a widespread interest. The Reynolds model [1] identifies the quantity of heat that can be evacuated during the change of phase of the flowing fluid. The approach gives satisfactory results. However, the adoption of the assumption leading to take the temperature of the water film as being equal to the average temperature between the entrance and exit of the column may affect the validity of these results.

The present study investigates the use of salty water available in large quantities as cooling fluid as well as its influence on the process of heat exchange. To this end, experiments at laboratory level are carried out using fresh and salty waters. Based on these results, a numerical approach for determining the evolution of the temperature of the film of water flowing over a wall, and the total heat flow exchanged developed. A comparison between these two parts of the investigation is also carried out. Nomenclature

A [m^2] Transverse section of the column

C_p [J/kgK] Specific heat capacity at constant pressure

h [W/m^{2}K] Local heat transfer coefficient (convection)

k [W/mK] Thermal conductivity

L [m] Length of the cooling tower

L_V [J/kg] Water latent heat of vaporization

Nu [-] Nüsselt Number

Pr [-] Prandlt number

$\dot{m}_c$ [kg/s] Compensation mass flow of water

$\dot{m}_a$ [kg/s] Mass flow of air

R [-] Residue

Re [-] Reynolds Number

S [m^2] Exchange area

T [K] Temperature of water film

T_{me} [K]Average temperature of water

T_{ma} [K]Average temperature of air

V_a [m/s]Air velocity

ω [-]Coefficient of over-relaxation

ρ [kg/m^3] Air density

μ [kg/ms]Dynamic viscosity of air

Φ [W/m^2]Flux exchanged

II. EXPERIMENTAL APPROACH

The cooling tower used to carrying out the experiments is specifically designed for simulating the real operating conditions of a tower. It is mainly equipped with an electric heating system, a circulating pump and of an air aspirator. It constitutes the perfect example of a heat exchanger without walls inside which circulate two fluids (represented by water and air) in opposite directions and between which the heat and mass transfers take place.

Hot water is pumped from a tank to the top of the column where it is uniformly distributed on the exchange plates. The water film is then exposed to a flow of air drawn from outside by a fan situated at the base of the column. When the air gets in contact with the film of water, its humidity increases leading to the decrease of the water temperature. The humidity is later recovered in the reservoir and the water is again re-circulated in the system.

The column is equipped with the necessary means to measure the temperatures, the pressures and the flow rates. The characteristic parameters [2] and performances of the cooling tower are mainly represented by the heating load, the flow rate of the incoming water and sucked air.

Three types of experiments are performed. The first deals with the influence of the variation of the heating load on the performance of the column while the second and third show the influence of water and air flow rates on these characteristics.

III. NUMERICAL APPROACH

The knowledge of the performances of the cooling tower such as efficiency and cooling domain requires the determination of the total heat flux exchanged represented by the sum of the heat fluxes exchanged through evaporation and forced convection, i.e.:

$$\left(\frac{\Phi}{S}\right)_{\text{Total}} = \left(\frac{\Phi}{S}\right)_{\text{Evaporation}} + \left(\frac{\Phi}{S}\right)_{\text{Convection}} \quad (1)$$

The heat flux exchanged through evaporation [3], that exchanged through forced convection [4] as well as the convective exchange coefficient [3] may be expressed respectively as:

$$\left(\frac{\Phi}{S}\right)_{\text{Evaporation}} = \dot{m}_c \, . L_v \quad (2)$$

$$\left(\frac{\Phi}{S}\right)_{\text{Convection}} = h\left(T_{me} - T_{ma}\right) \quad (3)$$

$$L_v = 2500{,}8 - 2{,}48\, T_{me} \quad (4)$$

where the compensation mass flow noted $\dot{m}_c$ is determined experimentally while the local heat transfer coefficient (convection coefficient) is derived through the Nüsselt number [5]. The expression of the local heat transfer coefficient depends on the flow regime represented by the Reynolds and Prandtl numbers.

For a laminar flow:

$$\text{Re} \le 3.10^5 \qquad Nu = 0{,}664\sqrt{\text{Re}}\,(\text{Pr})^{1/3}$$

and for a turbulent flow:

$$\mathrm{Re} \succ 3.10^5 \qquad Nu = 0{,}036\,(\mathrm{Re})^{4/5}\ (\mathrm{Pr})^{1/4}$$

with: $\mathrm{Re} = \dfrac{\rho V_a\, L}{\mu} = \dfrac{\dot m_a L}{\mu A}$ and

$$\mathrm{Pr} = \frac{\mu Cp}{k}$$

Replacing equations (2), (3) and (4) into equation (1) leads to the expression relationship expressing the total heat flux exchanged in the column as a function of the average temperature of the water:

$$\left(\frac{\Phi}{S}\right)_{total} = h\left(T_{me} - T_{ma}\right) + q_c\left(2500{,}8 - 2{,}48\,T_{me}\right)10^{-3}$$

(5)

The average temperature of air is determined experimentally while that of water is derived through the solution of the heat equation applied to a film of water laying on a wall of known dimensions. In stationary regime, this equation reduces to the Laplace relationship:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \qquad (6)$$

The boundary conditions on all four sides of the plate may be expressed as:

$$\begin{cases} T(x,y) = T_{ma} & \text{For } x = 0{,}14cm \text{ and } y = 0 \\ T(x,y) = \dfrac{T_5 + T_6}{2} & \text{For } y = 8cm \end{cases}$$

A finite difference approach is applied to the partial differential equation of elliptic type (6). For internal points, this equation reduces to [6]:

$$T_{i+1,j} + T_{i-1,j} + T_{i,j+1} + T_{i,j-1} - T_{i,j} = 0 \qquad (7)$$

Developing this scheme for each node of the mesh provides a system of equations of (13 x 6) unknowns. An iterative procedure is applied to the solution expressed as [7]:

$$T_{IJ}^{(P+1)} = T_{IJ}^{(P)} + \frac{1}{4}\omega R \qquad (8)$$

where ω is the coefficient of over-relaxation whose value is 1.5. The water temperature is expressed as the arithmetic average of the temperature nodal values of the film of water.

RESULTS AND DISCUSSION

This present investigation attempts to contribute to the study of the transport phenomena of heat and mass taking place in a cooling tower. It is mainly based on the experimental results obtained at laboratory level, but also on the computation of the average temperature of the film of water.
The distribution of the temperature of the flowing wat

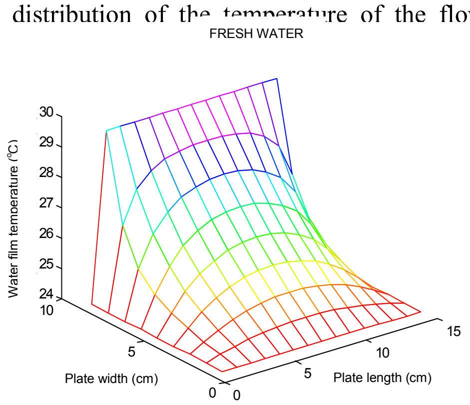

Fig. 1 Distribution of the temperature of water film on the filling plate-Fresh water case

It shows important values of the temperature on the higher side of the plate justified by the fact that hot water is poured out from the top of the plate down to its bottom side. Figure 1 shows the temperature distribution of the film in the case of fresh water. The temperature is found equal to 30°C on the upper side of the plate and decreases to the value of 24°C.
The same observation can be made for the case of salty water (c.f. Figure 2) but with a lighter decrease, leading primarily to the fact that fresh water shows a greater ability for heat transport.

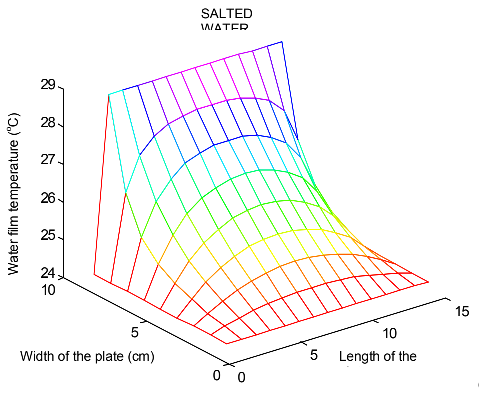

Fig. 2 Distribution of the temperature of the water film on the filling plate-Salted water case

Figure 3 shows the variation of the performance of the tower as a function of the heating load.
The inverse proportionality between these two parameters leads to the restriction of the cooling ability of the tower. A preponderance of the freshwater over the salty water in terms of performance is also noticed.

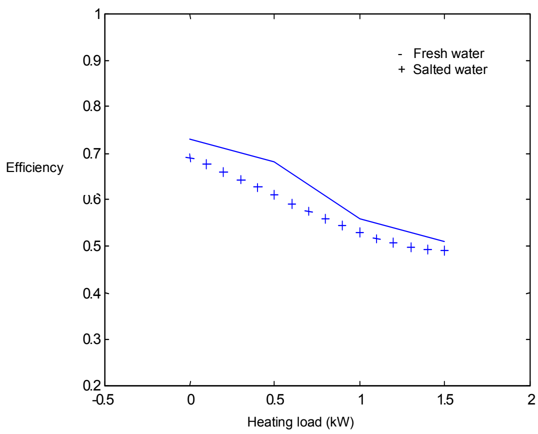

Fig.3 Efficiency variations as a function of heating load

The influence of water flow rate on the tower performance is represented in Figure 4.

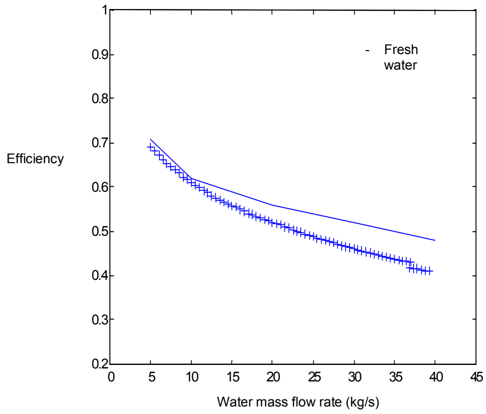

Fig. 4 Efficiency variations as a function of the mass flow rate of water

The shape of the decreasing curve indicates that the amount of water injected has a similar impact to that of the heating load (c.f. Figure 3). These behaviors limit the use of the tower to heating loads and water flow rates in the range of 0kW-1kW and 5kg/s-25kg/s respectively.
The variation of the cooling efficiency with the airflow rate is an increasing curve (c.f. Figure 5). The preponderance of fresh water over the salted is also noticed. Figure 5 shows fresh water having better cooling abilities than salted water. An optimal operation of the tower is determined for an airflow rate corresponding to 20mmH_2O.

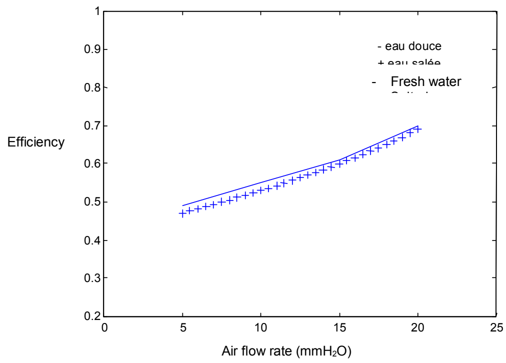

Fig. 5 Efficiency variation as a function of the airflow rate

An increase of the heating load tends to reduce the gap between the water temperatures at the entrance and exit of the column. The relationship between these two parameters shown in Figure 6 is similar to that linking the efficiency to the heating load, the influence of this latter being stronger. The slopes of two curves representing the fresh and salted water are shown to be essentially similar.

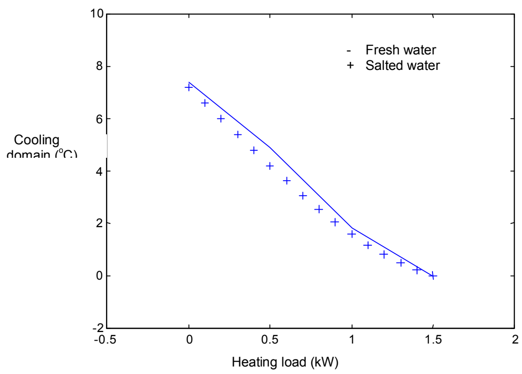

Fig. 6 Influence of the heating load on the cooling domain

The impact of the water flow rate is shown to be identical to that of the cooling load (cf. Figure 6 and Figure 7).

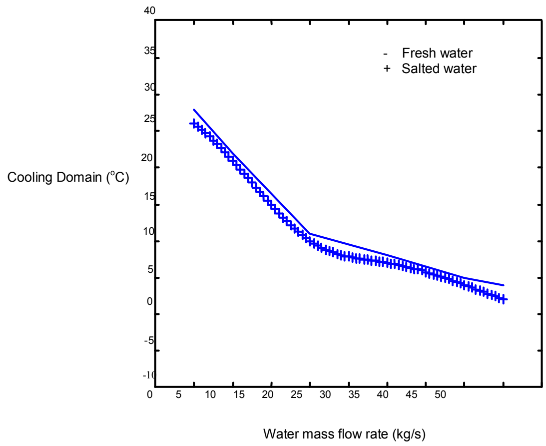

Fig. 7 Influence of water mass flow rate on the cooling domain

The curves representing the influence of the water flow rate on the cooling domain (cf. Figure 7) show a

less pronounced slope than those showing the influence of the increase of the water flow rate on the entrance and exit temperature gradients (cf. Figure 6).
A significant proportionality is found between the airflow rate and the cooling domain. This relationship is represented in Figure 8, and shows the influence of the flow rate of the air on the cooling domain.

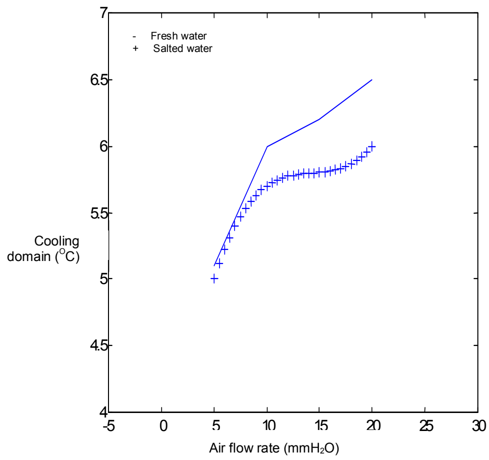

Fig.8 Influence of airflow rate on the cooling domain

An optimal operation of the tower represented by a maximum difference between the inlet and outlet water temperatures is represented by an airflow rate corresponding to 10mm H_2O.
The influence of the cooling load and water mass flow rate on the wet-bulb thermometer measurements are shown in Figure 9 and Figure 10 respectively. It may be seen that an increase of the heating load leads to a decrease of the temperature gap between water and air at the inlet (cf. Figure 9).

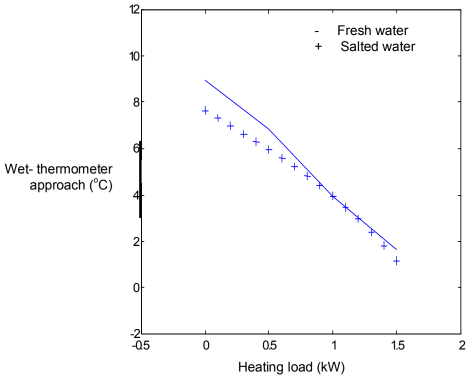

Fig.9 Influence of the cooling load on the bulb thermometer measurements

The same behavior is noticed with the water flow rate (cf. Figure 10).

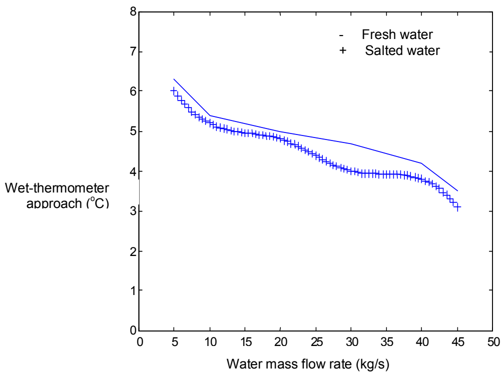

Fig. 10 Influence of the water mass flow rate on the wet-bulb thermometer measurements

An inverse proportionality is observed between these two parameters (heating load and water flow rate) and the wet-bulb thermometer results. A value of water mass flow rate of 20kg/s may be considered as an optimum point of operation of the cooling tower.

The flow of air sucked in can naturally increase the gap between water temperatures and air at the entrance of the column. Figure 11 shows a significant growth of this gap that may reach a value 9°C for an airflow rate corresponding to $20mmH_2O$.

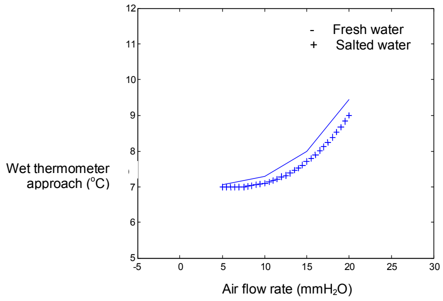

Fig.11 Influence of the air flow rate on the wet-bulb thermometer measurements

III. CONCLUSION

The present study concerns the experimental investigation carried out on a cooling tower at laboratory level. The experiments are carried out using both fresh and salty water as cooling fluids, the purpose being to highlight the influence of various characteristic parameters such as the cooling load, the velocity of the air and the mass flow rate of water. The cooling characteristics of fresh water and salty water as also investigated.

The investigation is also interested by the determination of the average temperature of the film of water flowing on the tour plate leading to a better understanding of the phenomena as well as a computation of the total heat flux exchanged in the tower. The results obtained using fresh water and salty water and their comparison lead to the following conclusions:

- Fresh water shows a greater cooling capacity than salty water. This feature is noticeable for the efficiency of the tower, the cooling domain it develops as well as the results of the wet-bulb thermometer.

water quantities that might not be available, or if available have to be used in more needed applications such as drinking). The availability of salty water (seawater) becomes in this case highly interesting.

IV. REFERENCES

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