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Effect of climate conditions and some operating parameters on pressure drop and heat and mass transfer characteristics of cooling tower in refrigeration and air conditioning systems

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Abstract

This paper presents some experimental results in effect of climate conditions, cooling demand and structure of the specific packed-bed on heat and mass transfer characteristics and pressure drop of Cooling tower (CTW) in lab-scale refrigeration and air-conditioning systems and industrial ones as well. Based upon such experimental results, a correlation was developed to estimate heat transfer characteristics of Cooling towers that would be a useful tool for proper design and operation of Cooling towers.

Keywords: Cooling tower, Heat and mass transfer, Cooling, Hot and humid climate, Pressure drop.

1. INTRODUCTION

Cooling towers of refrigeration and air conditioning systems are mixed convection heat transfer devices. In the hot and humid condition of Vietnam, CTWs don't work effectively, not as good as it's designed to be.

The reduction in cooling efficiency is often solved by replacing the structure, the height of packed bed of CTWs. However, when the structure and the height of packed bed change, it often leads to an increase in resistance loss and a change in heat and mass transfer characteristics [1]. To solve this problem, it is necessary to research changes in pressure drop and heat - mass transfer characteristics of CTWs working in hot and humid conditions with different structures and heights of packed bed, thereby determine reasonable working condition of CTWs.

2. EXPERIMENTAL WORK

2.1 Experimental study models

The process of experimental study was conducted on laboratory equipment which is available at School of

Heat Engineering and Refrigeration [5] (Pic.1 a) with different structures and heights of packed bed (Pic.1 b). To verify experiemental data with the reality, the experiment will also be conducted on some CTWs in different provinces such as Ha Noi, Thanh Hoa, Nghe An, Ha Tinh and Quang Binh. ..

Table 1. *Limit on some parameters in experiments*

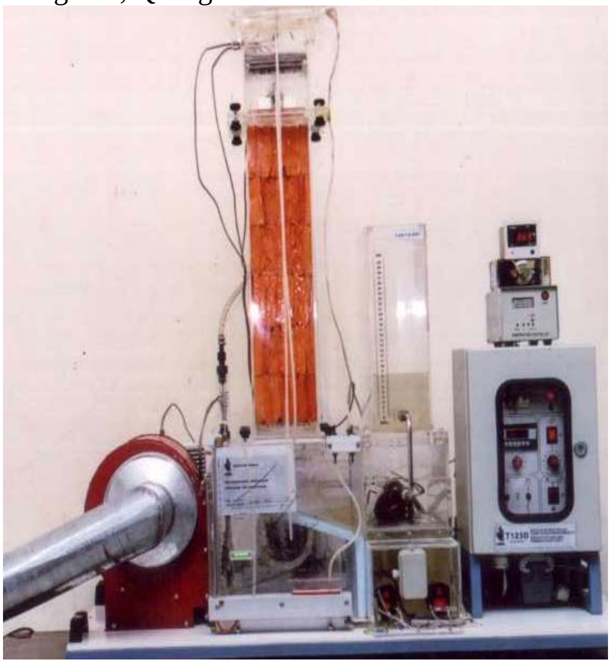
No.	Parameter	Symbol	Experimental values
1	Water temperature inlet the CTW, ^oC	t_{w1}	35, 38, 40, 42, 45
2	Air temperature inlet the CTW, ^oC	t_{a1}	25, 28, 30, 32, 35
3	Humidity in CTW, %	φ_1	60, 65, 70, 75, 80,85, 90
4	Ratio of air and water	μ	1; 1,25 ; 1,5; 1;75; 2; 2,5
5	Specific surface area, m^2/m^3	F	0, 25, 125, 160, 200, 250, 300
6	Height of packed bed, mm	H	150, 300, 450, 600, 750

A experimental condition is a process of measuring and determining cooling efficiency, volume of evaporated

water, pressure drop... of CTWs when some factors change as below.

The CTWs, which are measured in reality, are: the CTW of Hai Ha confectionery company, Garment company, Pharmaceutical company, Vietnam News Agency in Ha Noi; the CTW in Phuong Dong Hotel in Nghe An; the CTW in Ha Tinh

Beer factory; the CTW at Television station in Dong Hoi, Quang Binh.



a. Experimental study model

b. Some types of structures of experimental packed bed.

Pic.1 Experimental study model and some types of structures of experimental packed bed

2.2 Measuring device

Temperature measuring system of the model has accuracy of 0.1 K; water flow; air flow, amount of evaporated water and pressure measurement has accuracy which meets with the experimental requirements. [1]

Temperature and humidity measuring devices TESTO 400 (Germany) and flow measuring device DWYER (USA) were used to measure in the field. These devices have high precision and have been tested to ensure the required accuracy for the experiment. [1]

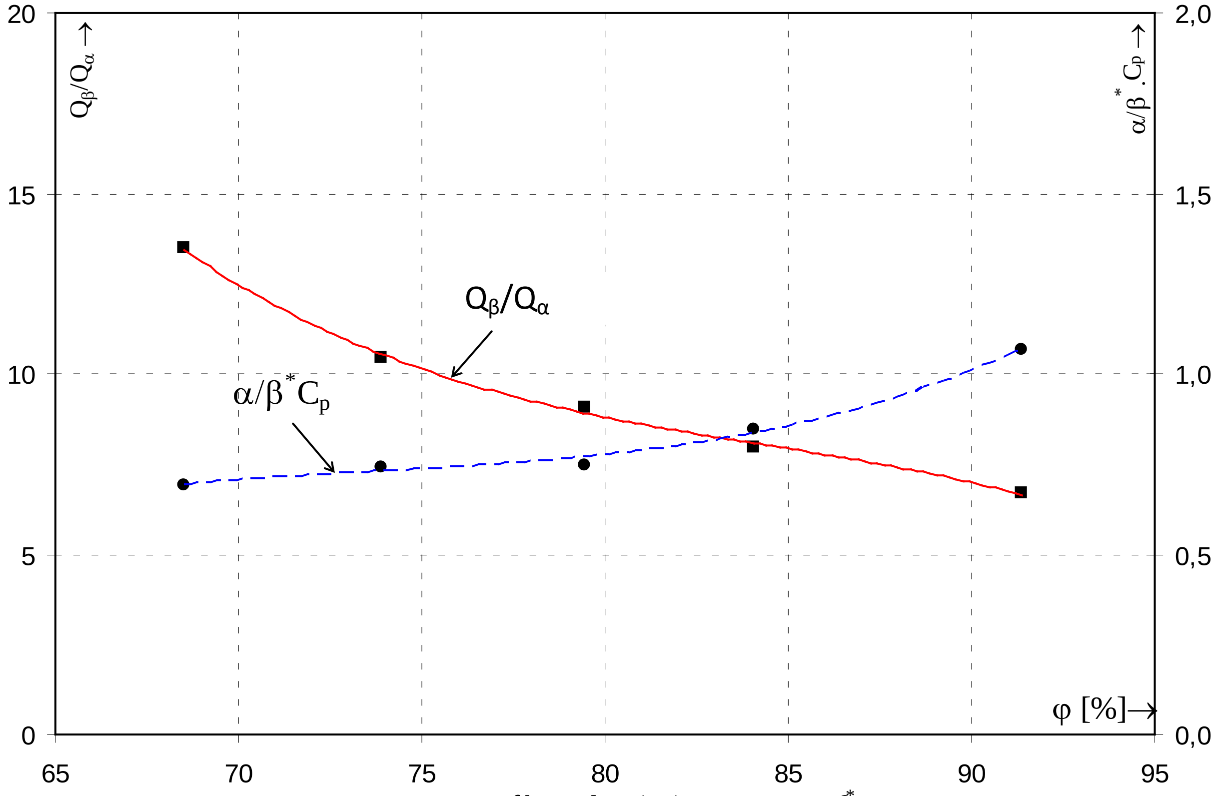
2.3 Experimental result and evaluation

301 experimental conditions on experimental model and 26 experimental conditions on CTWs in reality were carried on. Each experimental condition is measured 5 times. Experimental result is the average of 5 times of measurement with relative random error of 0.32% on model and 1.15% on CTWs in reality.

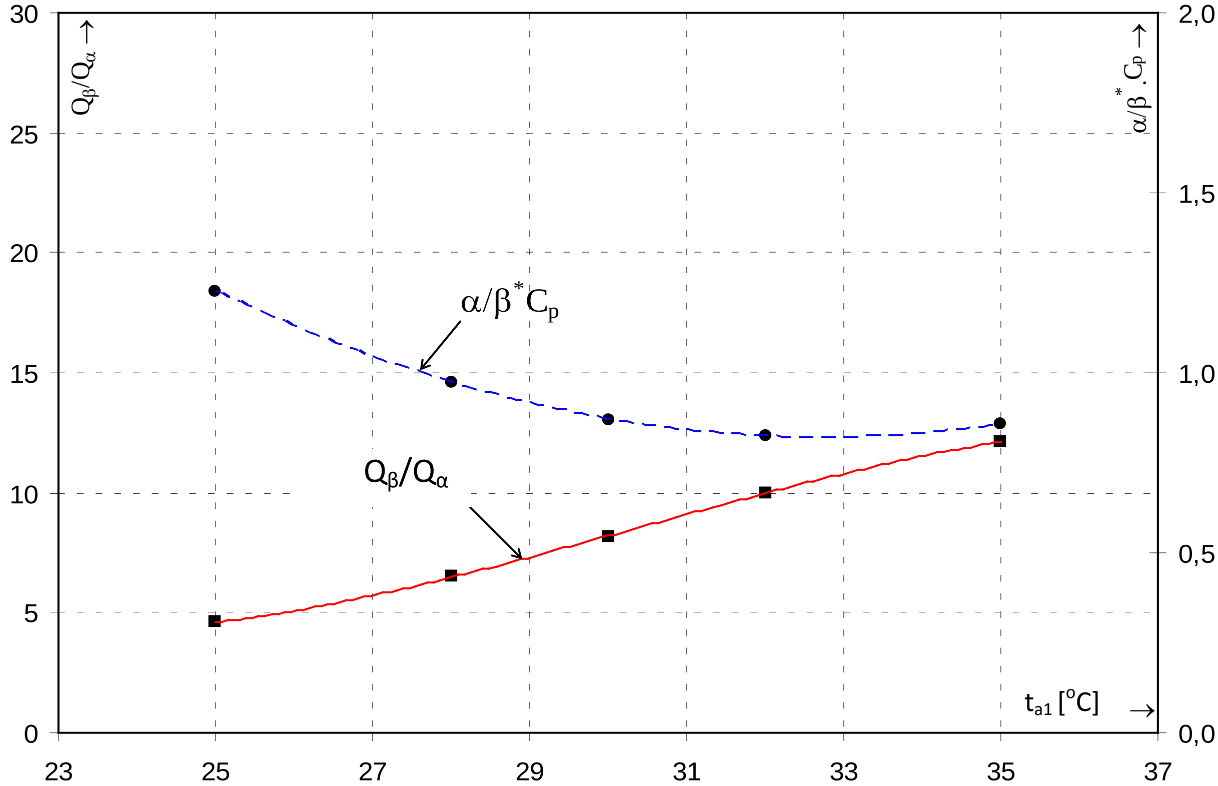
Based on the experimental results obtained, the impact of factors: temperature (t_{a1}), humidity (φ_1) in the air, specific area of packed bed surface (f), the height of packed bed, temperature of water needed to be cooled (t_{w1}) and irrigation coefficient (μ) on the amount of evaporated water and cooling effect of CTWs have been identified and shown on the Pic 2, 3, 4, 5, 6, 7.

The study shows that: in CTWs, the transfer of heat via mass transfer is dominant, accounting for over 80% of total quantity of transferred heat. In hot and humid climate, when humidity increases, the transfer of heat via mass transfer decreases (Pic 2). In particular, Q_β/Q_α falls from 12.5 to 7 and $\alpha/\beta^*.C_p$ rises from 0.71 to 1.04 when φ_1 increases from 70% to 90%. When t_{a1} increases from 25°C to 35°C, the percentage of Q_β/Q_α surges from 4.8 to 12 times and specific combination $\alpha/\beta^*.C_p$ drops from 1.23 to 0.86.

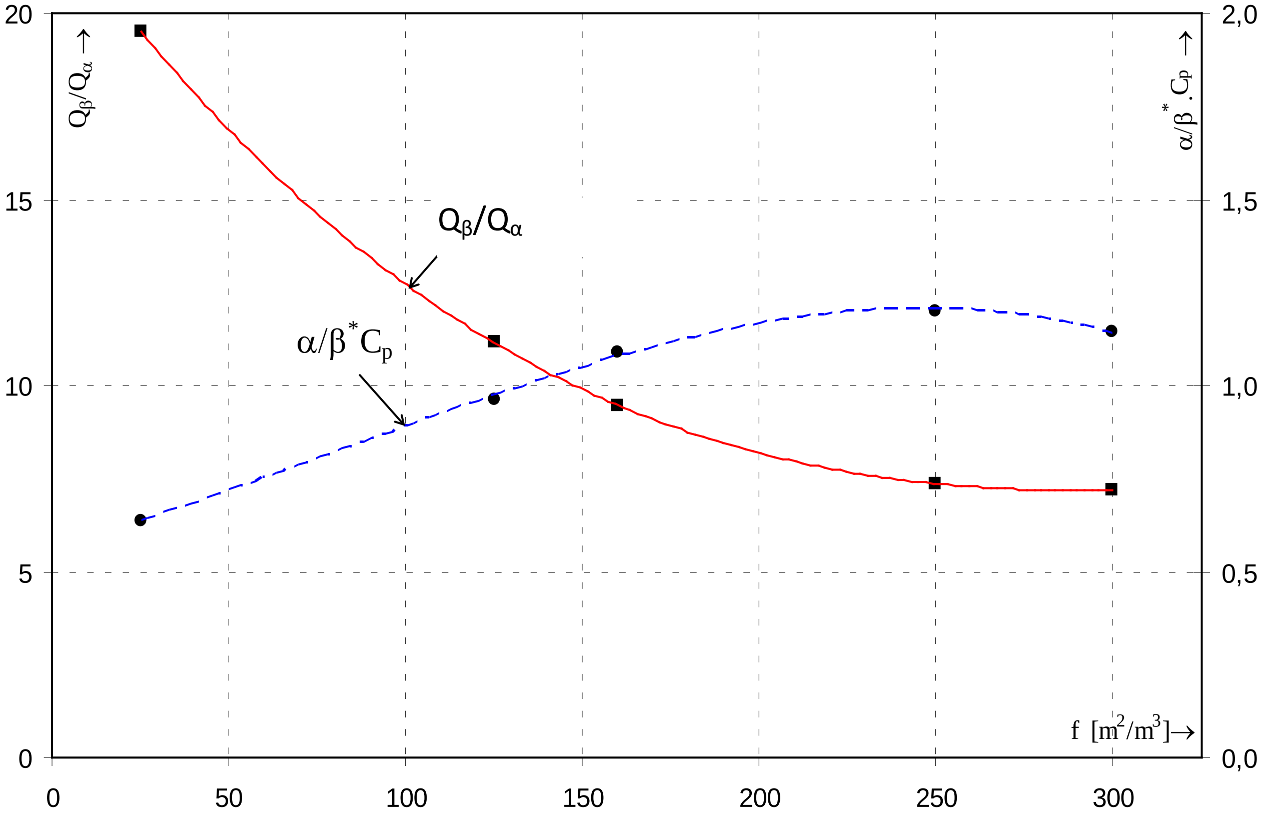
The structure characteristics and the height of packed bed have great influence on heat and mass transfer in cooling towers. In particular, when f rises, $\alpha/\beta^*.C_p$ rises, but Q_β/Q_α drops, and almost stays unchanged when f > 250 (Pic 4). When H increases, $\alpha/\beta^*.C_p$ increases and the percentage of Q_β/Q_α decreases, but the change is trivial when H > 600 mm. (Pic 5)



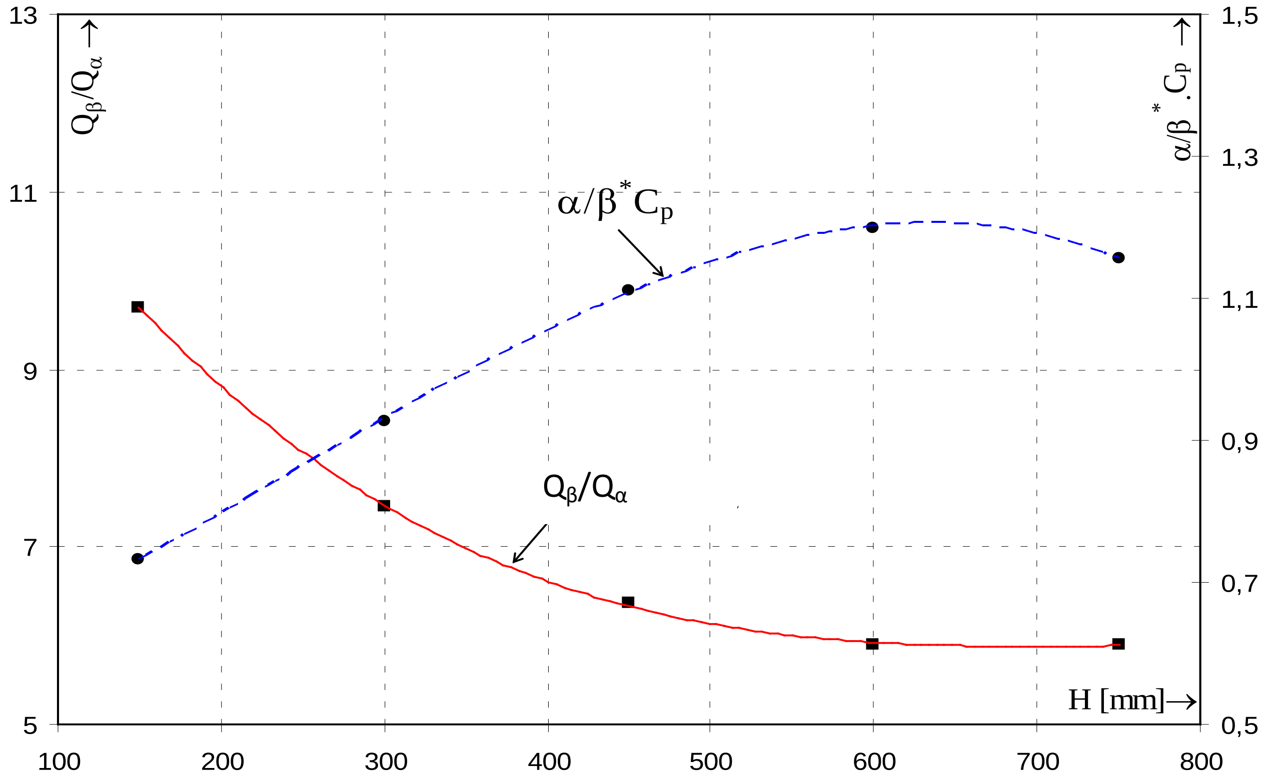
Pic.2 *Impact of humidity* (φ_1) *on* Q_β, Q_α, $\alpha/\beta^*.C_p$



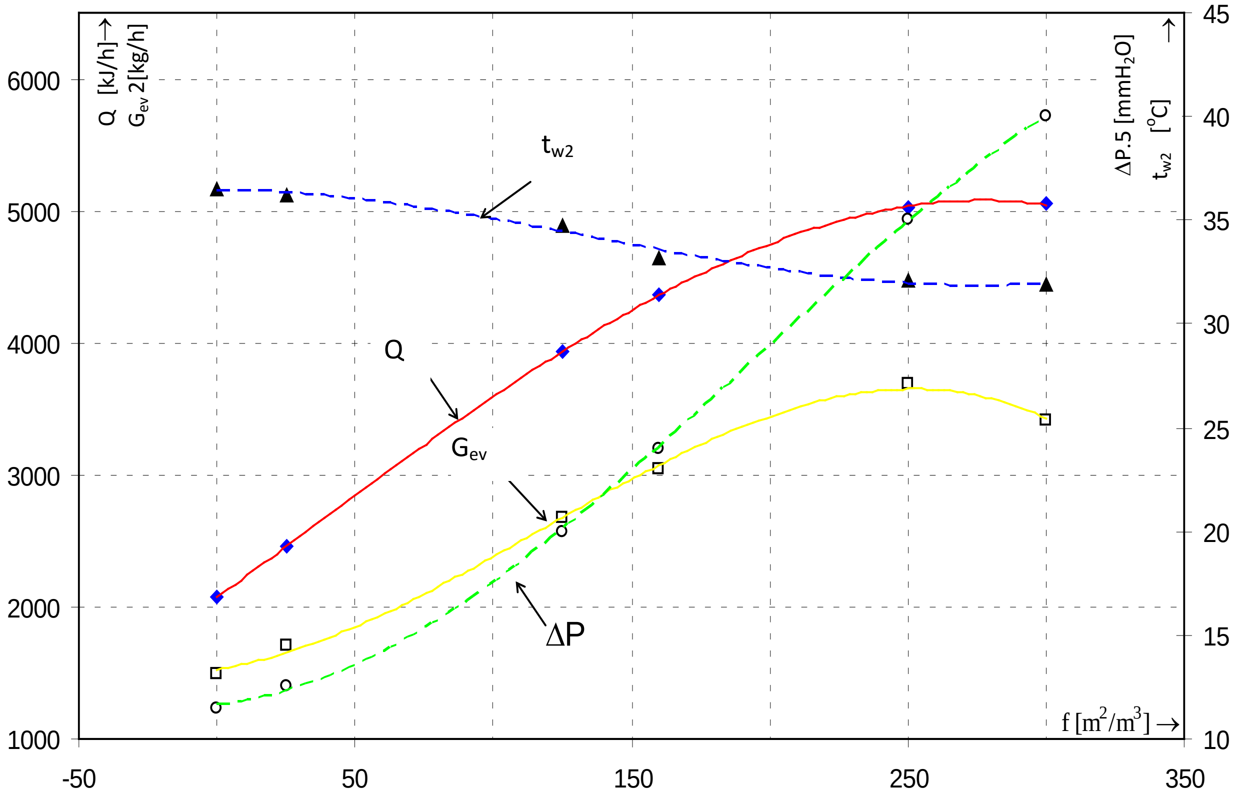
Pic.3 *Impact of temperature of the air* (t_{a1}) *on* Q_β, Q_α, $\alpha/\beta^*.C_p$



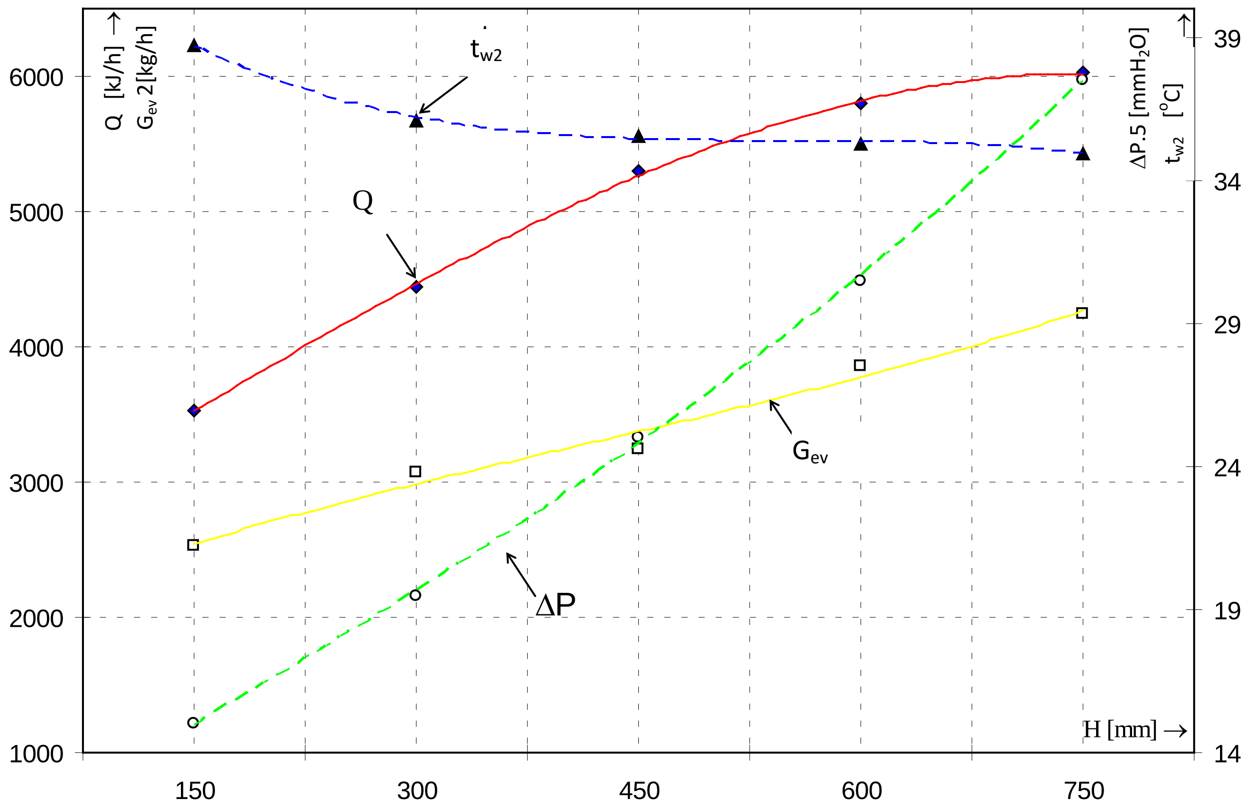
Pic.4 *Impact Specific surface area (f) on* Q_β, Q_α, $\alpha/\beta^*.C_p$



Pic.5 *Impact of Cooling tower packing height (H) on* Q_β, Q_α, $\alpha/\beta^*.C_p$



Pic.6 *Impact of Specific surface area (f) on* t_{w2}, *Q*, G_{ev}, η



Pic.7. *Impact of Cooling tower packing height (H) on* t_{w2}, *Q*, G_{ev}, η

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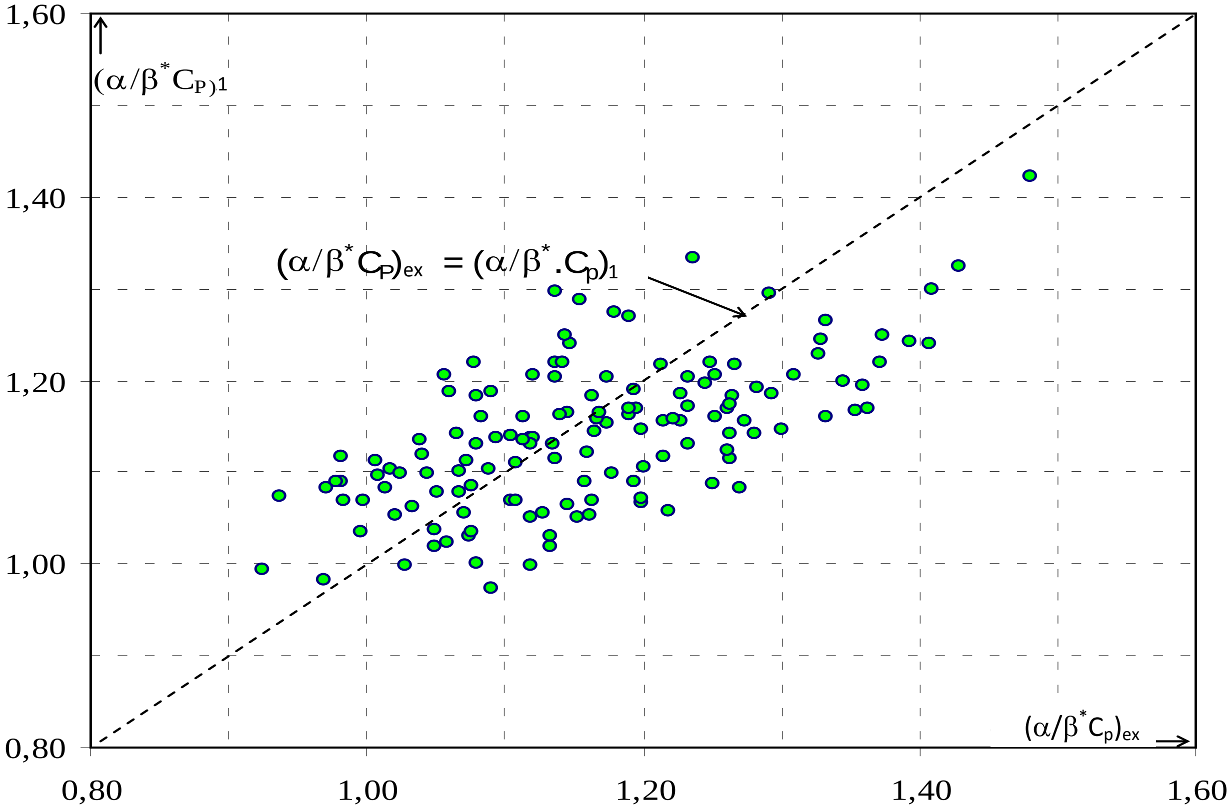

Pic.8 *Compare values of* $\dfrac{\alpha}{\beta^* C_p}$ *calculated with standard equation (1) and experiment*

In the experimental limit, when f increases from 0 (no packed bed) to 300 m^2/m^3, pressure drop ΔP rises constantly from 2.1 mm H_2O to 8.0 mmH_2O and it nearly rises linearly (Picture 6). However, when f increases from 0 to $250m^2/m^3$, t_{w2} drops by 9% and Q rises by 60%, but when f climbs up to 300 m^2/m^3 t_{w2} only falls by 0.1%, Q almost remains unchanged.

When H goes up from 150mm to 750mm pressure drop ΔP increases constantly from 3.0 to 7.5 mmH_2O and gradually climbs from 20% to 30% (Picture 7). But when H rises from 150mm to 600mm, the increase of Q decreases from 38% to 20% and the decrease of t_{w2} is from 6% to 3% and Q, t_{w2} almost stay the same when H goes up over 600mm.

3. FORMING STANDARD EQUATIONS

Heat and mass transfer is a process of complex mixed energy exchange. To generalize the study results, combining experimental study results with similarity theory, to form dimensionless equation determining the characteristics of heat and mass transfer of CTWs, working with feature of packed bed and hot – humid climate in Vietnam. [1]

The equation to identify specific combination has its form as below:

$$\frac{\alpha}{\beta^*.C_p} = 0,9416.\left(\frac{t_{k1}}{t_{n1}}\right)^{-1,1469}.\left(\frac{t_{u1}}{t_{n1}}\right)^{0,7579}.\left(\frac{G_k}{G_{n1}}\right)^{0,1938}.(f.H)^{0,0175} \quad (1)$$

The value of specific combination of heat and mass transfer is identified, using the equation (1) and experiment in the same condition is presented in Picture 8. The average deviation between results from the equation (1) and the experiment is 4.91% and all of these values fluctuate round the main diagonal line. With this deviation, the result of calculating specific coefficient combination in accordance with (1) is reliable. The average result of α/β^*C_p combination of CTWs working in hot and humid environment is 1.16.

4. CONCLUSION

From the study results we can draw some conclusions:

1. In CTWs, transfer of heat via mass transfer is dominant; with hot and humid climate, the quantity of heat transferred via mass transfer

accounts for over 80% of total quantity of heat transferred and specific combination $\alpha/\beta^*.C_p$ is 1.16 at average, higher than the study result of Lewis (=1) and of Bosnjakovic (<1) [1], [4], [5]

2. The specific surface area and the height of packed bed has great influence on pressure drop and the characteristics of heat and mass transfer of CTWs. However, when f > 250m^2/m^3 and H > 600mm, ΔP continues to rise and rise higher and higher, heat output and temperature of water needed cooling remain unchanged.

3. Standard equation is formed from the result of experimental study, verified with practical survey and it enables to identify specific value of heat and mass transfer with high accuracy. This is a reliable and useful tool in study, calculation, design and operation of CTWs.

5. NOMENCLATURE

Symbol	Name		
F [m^2]	Surface area		
G [kg/s]	Mass flow		
H [m]	Height of CTW packing		
Q [W]	Heat flux		
T [^{o}C]	Temperature		
F [m^2/m^3]	Specific surface area		
C [kJ/kgK]	Specific heat capacity		
φ [%]	Relative humidity of the air		
α [W/m^{2}K]	Convective heat transfer coefficient		
β [kg/m^{2}sPa]	Mass transfer coefficient		
β^* kg/m^{2}s]	Combine transfer coefficient		
η [%]	CTW performance		
ΔP mmH$_2$O]	Pressure loss		
μ	Ratio of water and air flows		
Subscript			
1	In	w	Water
2	Out	ma	mass transfer
Ev	Evaporate	ex	Experimental
a	Air	wb	Wet bulb
co	Convection	av	Average
p	Constant pressure		

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Dang Tran Tho was born in, Ha Tinh Province of Viet Nam on 20th May 1977. He got Engineer’s and PhD degrees from Ha noi University of science and technology in 2001 and 2008, respectively. Since 2001, he has been a lecturer at the School of Heat Engineering and Refrigeration of Ha noi University of Science and Technology.

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