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Effect of Climate Conditions and Some Operating Parameters on Water Evaporation of Cooling Tower in Refrigeration and Air Conditioning Systems

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Abstract: *The article presents an experimental study on effect of warm and wet climate conditions, cooling requirement, and specific packed bed to the amount of make-up water for the cooling towers in lab-scale refrigeration and air-conditioning systems and industrial ones as well. Based upon the experimental results, one standard correlation for estimate of the make-up water flow rate was developed. A good agreement between the experimental data and calculated results was observed that would reflect a possibility of employing the developed correlation in designing and operating cooling towers of refrigeration and air-conditioning systems under Vietnam climate conditions.*

Keywords: *Heat and mass transfer, Cooling tower, Cooling, Hot and humid*

1. INTRODUCTION

Refrigeration systems and complex air-conditioning systems often use water-cooled condenser along with cooling tower (CTW). A cooling tower is a heat exchanger of mixture, special contact. Cooling effect of cooling towers is related to effect of evaporation of water and air. But in warm and wet climate conditions in Vietnam, cooling towers don't work well and have differences [1], [2], [3]. Making up for the water of available cooling towers which is continuously evaporated into the air should be calculated in accordance with technology requirement and typical climate conditions in Vietnam. To solve this problem, it's necessary to re-calculate on the basis of research of heat exchanger of cooling towers in warm and wet climate conditions, technology requirement, specific packed-bed, then determine cooling efficiency and volume of make-up water needed for cooling towers in order to set up optimal working mode for the system.

2. EXPERIMENTAL WORK

2.1. Experimental Study Models

Experimental study process is conducted on the basis of experiment device T123D, which is available at School of Heat Engineering and Refrigeration [4], (Picture 1.a). Besides, experimental process will also be conducted on some cooling towers in reality (Picture 1.b) in some different provinces such as: Ha Noi, Thanh Hoa, Nghe An, Ha Tinh, Quang Binh where the climate is typical [1].

Below are conditions for experiment study.

2.1.1. Climate Condition

- Temperature of the air going into the tower, t_{a1}: 25, 28, 30, 32, 35 ^{o}C;
- Humidity of the air going into the tower, φ_1: 60, 65, 70, 75, 80, 85 90 %.

2.1.2. Feature of Packed Bed

- Specific surface area, f: 0, 25, 125, 160, 200, 250, 300 m2/m3;
- Height of packed bed, H: 150, 300, 450, 600, 750 mm.

2.1.3. Technology Requirement

- Temperature of water needed to be cooled, t_{w1}: 35, 37, 40, 42, 45 ^{o}C;

- Irrigation coefficient, μ: 0,5; 1; 1,5; 2; 2,5.

The cooling towers that are measured and surveyed in reality are:

- The cooling towers in Hai Ha confectionery company, Garment company, Pharmaceutical company, Vietnam News Agency in Ha Noi;
- The cooling towers in Phuong Dong Hotel in Nghe An;
- The cooling towers in Ha Tinh Beer factory;
- The cooling towers at Television station in Dong Hoi, Quang Binh.

a. Experimental study model *b. Experiment measurement*

Picture1. *Experimental study model and experiment measurement*

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]

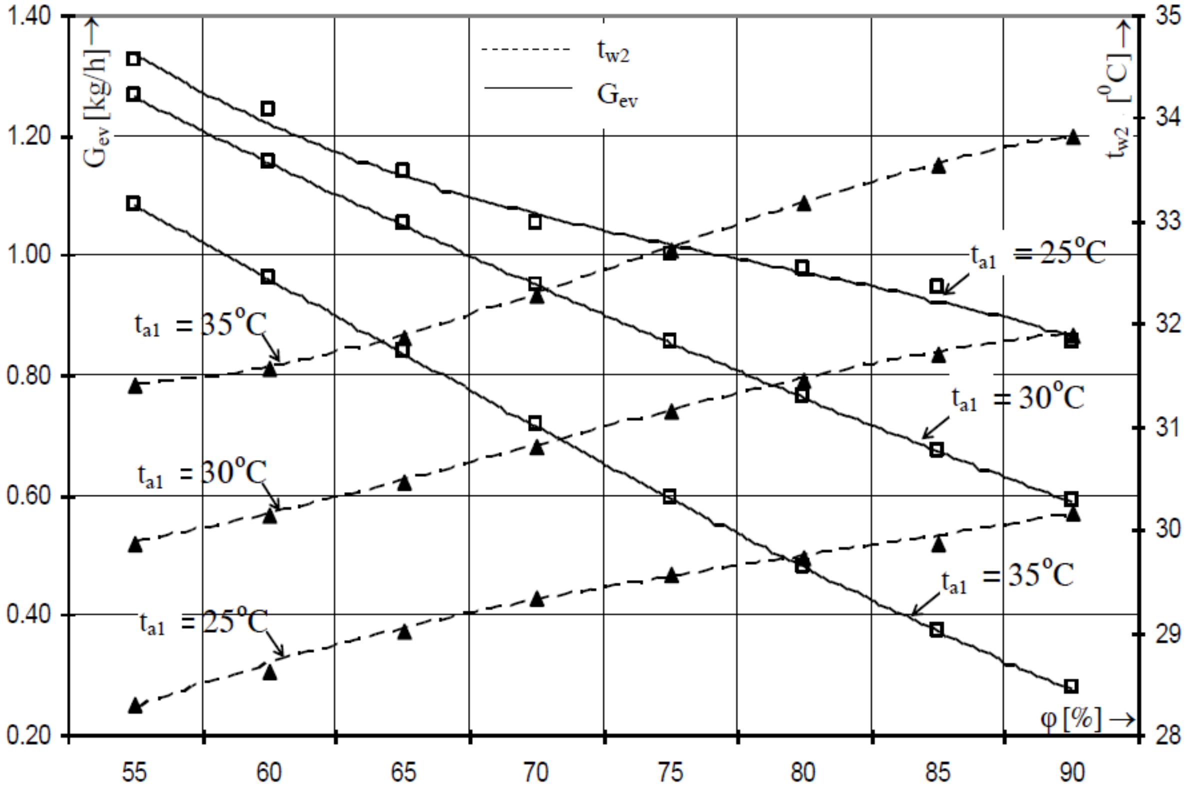
Temperature and humidity measuring devices TESTO 400 (Germany) and flow measuring device DWYER (USA) were used to measure in the field. These devices have high precision and have been tested to ensure the required accuracy for the experiment. [1]

2.3. Experimental Result and Evaluation

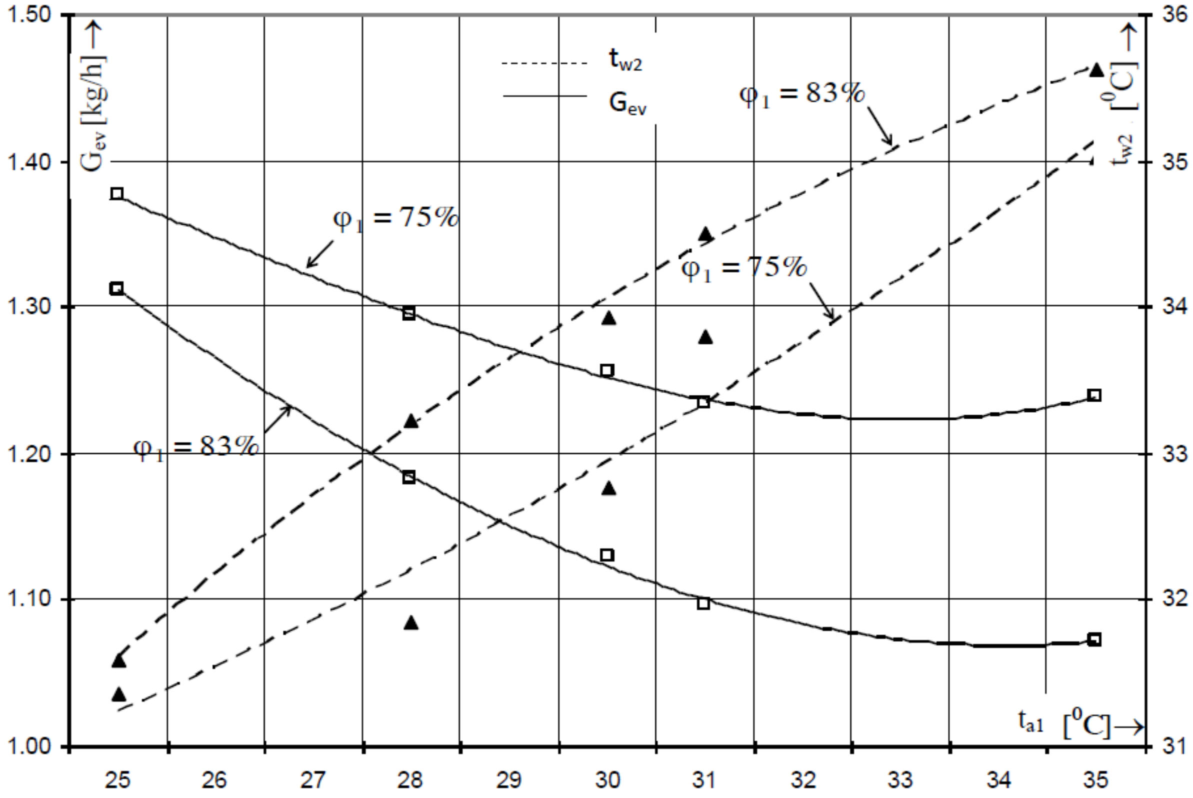
301 experimental conditions on experimental model and 26 experimental conditions on cooling towers in reality were carried on. Each experimental condition is measured 5 times. Experimental result is the average of 5 times of measurement with relative random error of 0.325 on model and 1.15% on cooling towers in reality.

For each experimental condition, cooling effect, evaporated water flow, pressure loss of cooling tower are all identified. [1]

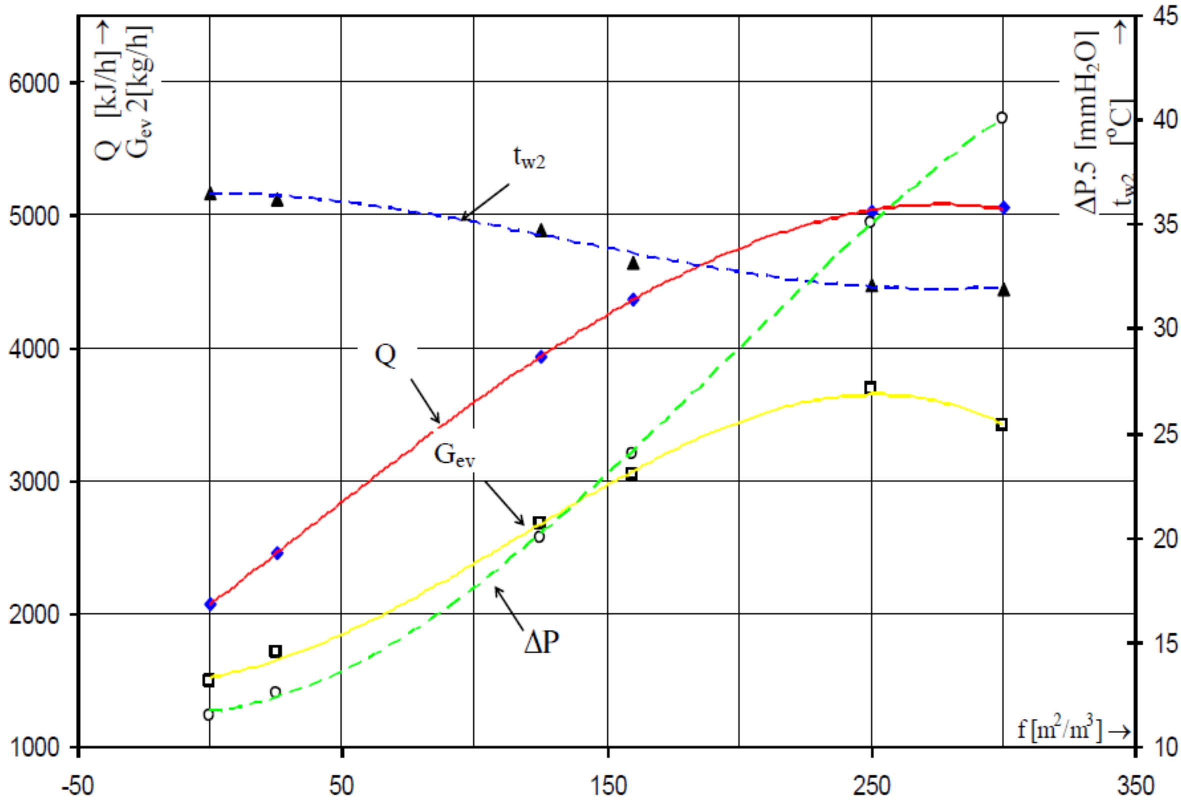
Based on the experimental results obtained, the impact of factors: temperature (t_{a1}), humidity (φ_1) in the air, specific area of packed bed surface (f), the height of packed bed, temperature of water needed to be cooled (t_{w1}) and irrigation coefficient (μ) on the amount of evaporated water and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



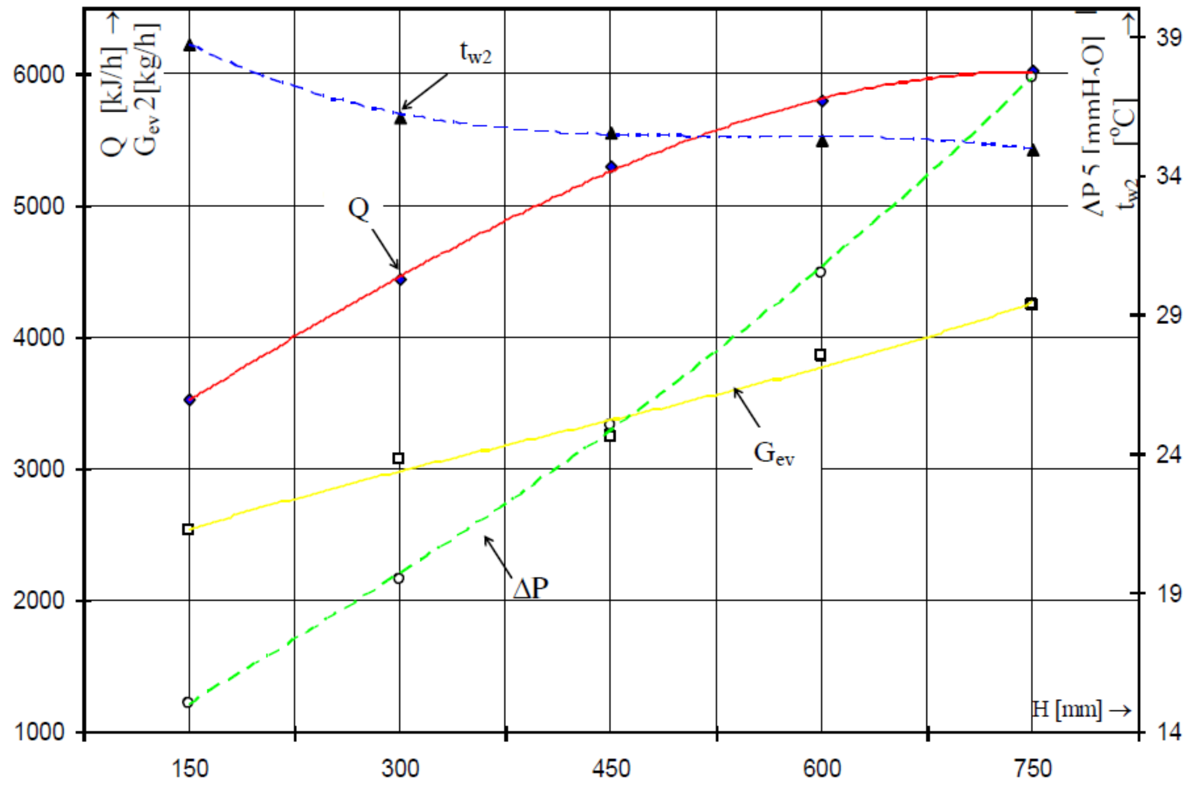
Picture2. *Impact of humidity (φ_1) on t_{w2}, G_{ev}*



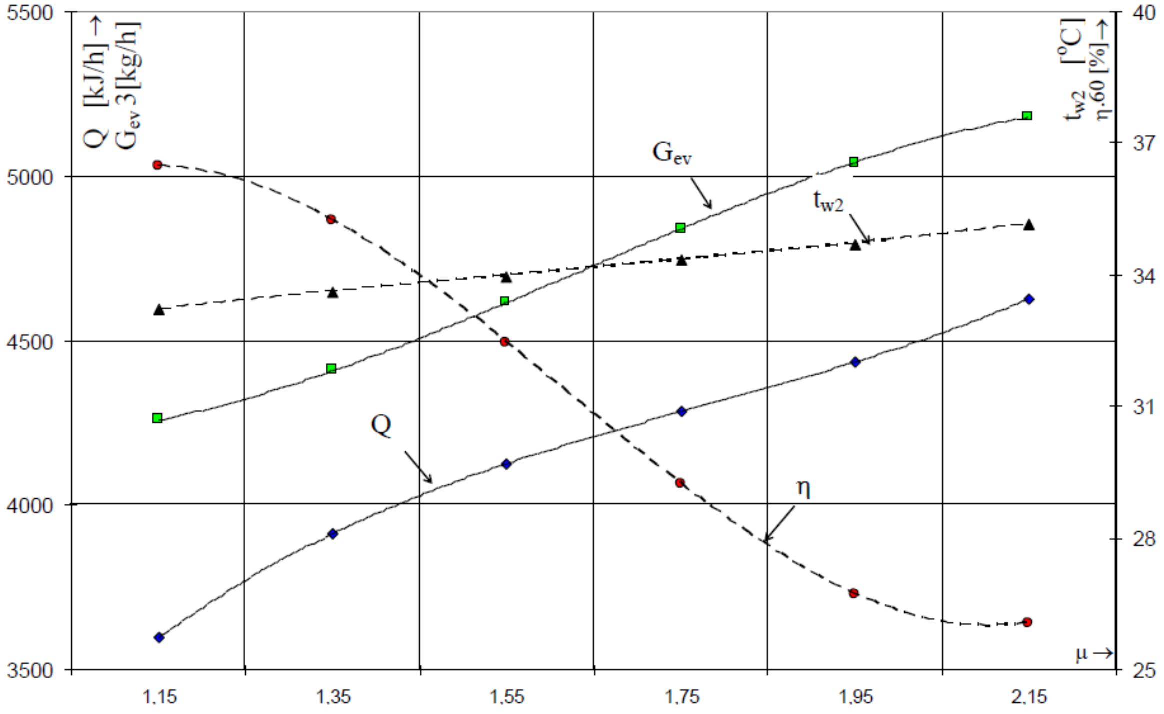
Picture3. *Impact of temperature of the air (t_{a1}) on t_{w2}, G_{ev}*



Picture4. *Impact of Specific surface area (f) on* t_{w2}, *Q*, G_{ev}, η



Picture5. *Impact of cooling tower packing height (H) on* t_{w2}, *Q*, G_{ev}, η



Picture6. *Impact of Ratio of water and air flows (μ) on t_{w2}, Q, G_{ev}, η*

Experimental survey results show that: when humidity increases from 60% to 90%, the flow of evaporated water G_{ev} decreases by 55% at average and temperature of cooling water rises by over 5%. (Picture 2)

When t_{a1}increases from 25°C to 35°C,temperature of water outflow t_{w2}goes up by 6,5% và G_{ev}falls by 18,94%. (Picture 3)

With$\varphi_1$increasing from 60% to 90% and t_{a1}rising from 25°C to 35°C, experimental results show that G_{ev}falls by 60% and t_{w2}rises by 10%.

In the experimental limit, when the specific surface area increases from 0 (no packed) to 250 m^2/m^3, the t_{w2} decreases by more than 9%, G_{ev} rises by more than 55%; when the specific surface area increases to 300 m^2/m^3, t_{w2} only decreases by 0.1% and G_{ev} starts to decline.

When H increases from 150 mm to 750 mm, t_{w2}drops by 12%, G_{ev}jumps by 44.57%. However, when H increases with the modules which have a constant height (150 mm), the increase of G_{ev}, the decrease of t_{w2} change and go down gradually. When H increases from 600 mm to 750 mm, the t_{w2} only decreases by 0.44%.

When μ drops from 2.15 to 1.15, then flow of evaporated water increases by more than 18% but cooling effect improves, after cooling t_{w2} decreases by 5.5%

3. STANDARD EQUATION

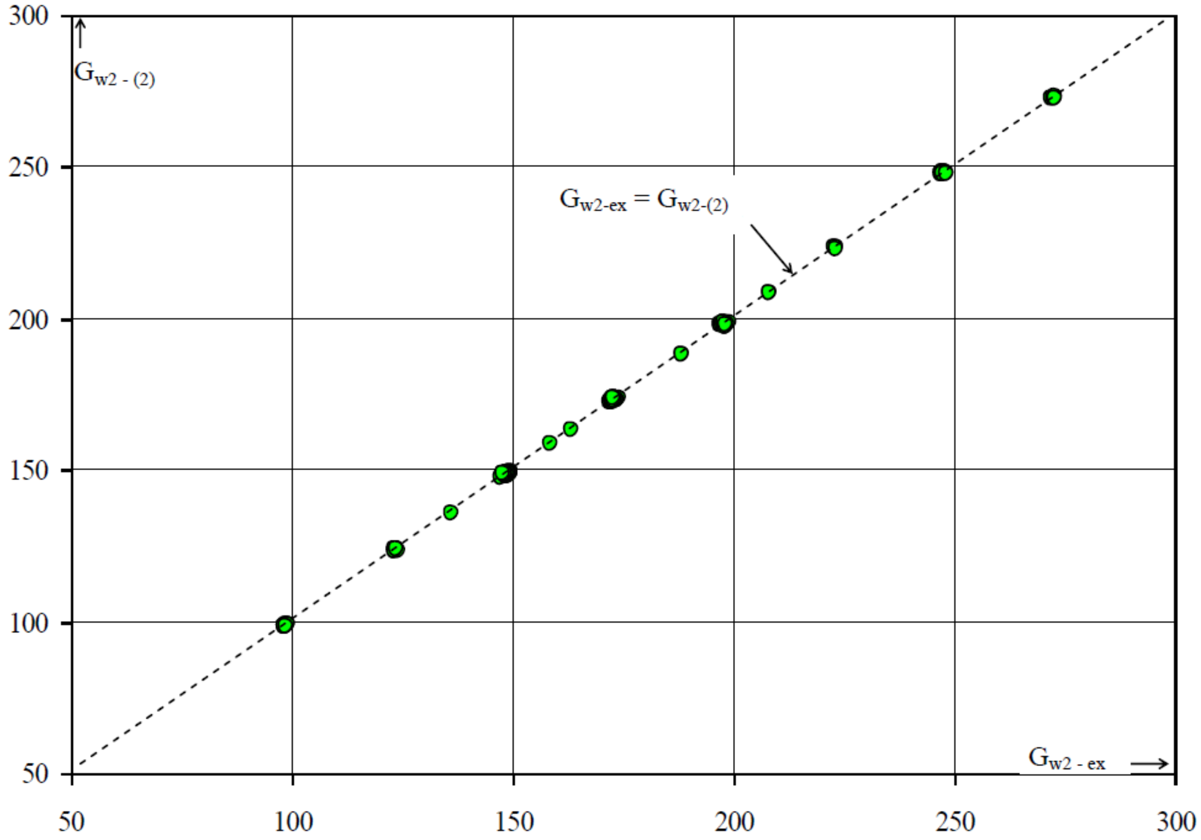
In order to generalize the research results, combiningexperimental study results with similarity theory, to form dimensionless equation determining the flow of evaporated water for cooling towers. Specifically, dimensionless equation determining water flow out of cooling towers $G_{w2}$is formed as below[1]

$$\frac{G_{w2}}{G_{w1}} = C.(\frac{t_{a1}}{t_{w1}})^{C_1}.(\frac{t_{wb1}}{t_{w1}})^{C_2}.(\frac{G_a}{G_{w1}})^{C_3} \quad (1)$$

From the experimental study results, the empirical coefficient C, C_1, C_2, C_3were identified. Put these values into the equation (1), we have the following equation to identify G_{w2}:

$$\frac{G_{w2}}{G_{w1}} = 0.9954 .(\frac{t_{a1}}{t_{w1}})^{-0.0057} .(\frac{t_{wb1}}{t_{w1}})^{0.0148} .(\frac{G_a}{G_{w1}})^{5.2974} \qquad (2)$$

Value of G_{w2}calculated according to the equation (2) and experiment in the same margin conditions are presented in Figure 7. The average discrepancy between the two results is: 0.15% and the maximum discrepancy is 0.45%.



Picture7. *Compare values of G_{w2} calculated with standard equation (2) and experiment.*

4. CONCLUSION

From the study results we can draw some conclusions:

1. The air temperature and humidity greatly affect the efficiency of cooling and amount of evaporated water of cooling towers, at average, with cooling towers designed in the temperate or polar regions, working in hot and humid climate, the make-up water flow decreases by more than 60% and the temperature of cooling water increases by a minimum of 2K.
2. Specific area and height of packed bed affect the cooling efficiency and the amount of make-up water for cooling towers. In study limitation when H ≥ 600 mm and f ≥ m^2/m^3, the efficiency of cooling and amount of make-up water are almost unchanged and then cooling towers work in an extreme mode which is not good for the system.
3. The standard equation, which is formed from experimental study results and tested through field surveys, allows accurate determination of water flow leaving the tower, thereby determining the amount of additional water for cooling towers. The average discrepancy is 0.45%. This is a reliable and useful tool in calculation, design, control and operation of cooling towers.

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Nomenclature

Symbol	Name	Subscript	
F [m^2]	Surface area	1	In
G kg/s]	Mass flow	2	Out
H [m]	Height of cooling tower packing	ev	Evaporate
Q [W]	Heat flux	a	Air
t	Temperature	w	Water
F [m^2/m^3]	Specific surface area	av	Average
φ [%]	Relative humidity of the air	ex	Experimental
η [%]	CTW performance	wb	Wet bulb
ΔP [mmH$_2$O]	Pressure loss		
μ	Ratio of water and air flows		

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Dang Tran Tho, was born in Huong Khe District, 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.

Dang Quoc Phu, was born was born in Cam Xuyen District, Ha Tinh Province of Viet Nam on the 6th August 1949. He got Engineer's and PhD degrees from Dresden University of Technology (Germany) in 1971 and 1976, respectively. Dr. Phu had been working for Ha noi University of Science and Technology during 1978-2013. In 1998, he was promoted as Professor in Thermal Technology. He died on 15th April, 2013.