Unviersty of Anbar

Anbar Journal Of Engineering Science©

journal homepage: http:// http://www.uoanbar.edu.iq/Evaluate/

Experimental study on thermal performance of counter flow wet cooling tower and effect of fins angle

Mr Hindren Ali Saber [a*], Assist Prof. Dr. Iyd Eqqab Maree [b]

[a] *Mechanical and Energy Engineering Techniques Department, Erbil Technical Engineering College / Erbil Polytechnic University (hindren81@gmail.com, hindren.ali@epu.edu.krd)*

[b] *Mechanical and Energy Engineering Techniques Department, Erbil Technical Engineering College / Erbil Polytechnic University (aiyed67@gmail.com, aiyed67@epu.edu.krd)*

PAPER INFO

Paper history:

Received … … …

Received in revised form … … …

Accepted … … …

Keywords:

Cooling Tower, Performance Characteristics, Mass flow ratio, Fins angles

ABSTRACT

The aim of this paper is to in investigate the performance characteristics of counter flow wet cooling towers experimentally by varying air and water temperatures, fins angle, rate of air flow, rate of water flow as well as the evaporation heat transfer, along the height of the tower.

The analysis of the theoretical results revealed before that the thermal performance of the cooling tower is sensitive to the degree of saturation of inlet air. Hence, the cooling capacity of the cooling tower increases with decreasing inlet air temperature whereas the overall water temperature fall is curtailed with increasing water to air mass ratio. From the experimental study the efficiency of the cooling tower and cooling tower characteristics are higher in case of low mass flow ratio due to higher contact area of water to air. Because of better contact area between airs to water the drop in performance of the cooling tower is less.

The effect of fins angle on the thermal performance of counter flow wet cooling tower was predicted. The experimental study showed that the cooling range, cooling coefficient, , heat load , change in air relative humidity and cooling tower effectiveness increased with increasing fins angles and optimum fins angle obtained from this experimental work was 70 degree, at this angle all cooling tower performance has been calculated were better.

While the approach increased with decreasing fins angles, the minimum approach was obtained for 70 degree fins angles and the maximum approach was obtained for 30 degree fins angles.

1. Introduction

Acooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. It is a wooden, steel or concrete structure and corrugated surfaces or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser is fed to the tower on the top and allowed to tickle in form of thin drops ass in figure (1). The air flows from bottom of the tower or perpendicular to the direction of water flow and then exhausts to the atmosphere after effective cooling. To prevent the escape of water particles with air, draft eliminators are provided at the top of the tower.

Cooling towers are equipment devices commonly used to dissipate heat from power generation units, water-cooled refrigeration, air conditioning and industrial processes. Cooling towers offer an excellent alternative particularly in locations where sufficient cooling water cannot be easily obtained from natural sources or where concern for the environment imposes some limits on the temperature at which cooling water can be returned to the surrounding [1].

More recently, Kloppers and Kroger [2] studied the loss coefficient for wet cooling tower fills. They tested trickle, splash and film type fills in a counter flow wet cooling tower with a cross sectional test area of 1.5 m × 1.5 m. They proposed a new form of empirical equation that correlates fill loss coefficient as a function of the air and water mass flow rates. There are several other mathematical models which can correlate heat and mass transfer processes occurring in wet cooling towers, such as the models proposed and discussed by Khan et al. [3] and Kloppers and Kroger [4], "V.G.A." type packing. This type of packing was first proposed for the mass transfer processes between gas and liquid and has not been used in cooling water systems using direct contact between water and air. Lemouari [5] and Lemouari and Boumaza [6, 7] used this packing in an evaporative cooling system to study its thermal and hydraulic performances. Therefore, this study presents an experimental investigation of the thermal performances of cooling towers filled with the "V.G.A." type packing. This packing consists of vertical grids disposed between walls in the form of zig-zag.

The principle of its performance is as follows: the gas (air) enters at the bottom of the tower and goes to the top of that while crossing several times the vertical grids, whereas the liquid (water) is introduced at the top of the tower and flows along the vertical grids. Jorge [8] studied the thermal performance of the cooling tower in chilled ceiling conditions. A mass transfer coefficient correlation is developed, and new variables are defined. Naphon [9] performed a study on the heat transfer characteristics of an evaporative cooling tower. The tower had 0.15 m × 0.15 m internal cross section and 0.48 m in height packed with eight layers of the laminated plastic plates. He presented theoretical and experimental results of the heat transfer characteristics of the cooling tower by making a comparison between them. However, the author did not suggest any empirical correlation for the heat transfer characteristics of the tower. Elsarrag [10] presented an experimental study and predictions of an induced draft ceramic tile packing cooling tower. He used a tower of 0.64 m2 cross section area and 2 m height with a filling portion of 0.8 m. Burned clay bricks were used as the packing material in his work. The author pointed out that the factors affecting the heat and mass transfer coefficients are the water to air flow rate ratio, the inlet water temperature and the inlet air enthalpy. Dr. Najim A. Jassim [11] investigated experimentally and theoretically the thermal performance of closed wet cooling tower. The theoretical model based on heat and mass transfer equations and heat and mass transfer balance equations which are established for steady state case. A new small indirect cooling tower was used for conducting experiments. The cooling capacity of cooling tower is 1 kW for an inlet water temperature of 38oC, a water mass velocity 2.3 kg/m2.s and an air wet bulb temperature of 26oC. This study investigates the relationship between saturation efficiency, cooling capacity and coefficient of performance of closed wet cooling tower versus different operating parameters such wet-bulb temperature, variable air-spray water flow ratio and cooling water inlet temperature. Results indicate that the capacity and saturation efficiency was found close to the related experimental results.

2. Theoretical Analysis

The important parameters, from the point of determining the performance of cooling towers, as shown from the figure (5) are:

Cooling range (Z): The difference in temperature between the hot water entering the tower and the cold water leaving the tower is the cooling range.

$$Z = T_4 - T_5 \tag{1}$$

Approach (a):

The difference the temperature of the cold water leaving the tower and the wet-bulb temperature of the air is known as the approach.

$$a = T_5 - T_{f1} \tag{2}$$

Cooling coefficient (μ):

The cooling coefficient it is the efficiency of cooling tower and given by:

$$\mu = \frac{T_4 - T_5}{T_4 - T_{f1}} \quad (3)$$

Water loss (Mw):

Cooling towers with open circuits lose a certain amount of water due to evaporation and equals to amount of makeup water required, water loss is given by:

$$Mw = (X_2 - X_1) \times \dot{m}_l \quad (4)$$

Heat load (Qw):

It is the amount of heat transfer from water in the cooling tower is given by:

$$Qw = \dot{m}_w \times cp_w \times z \quad (5)$$

Calculating of volumetric air flow ($\dot{m}_l$):

It is the amount of air mass flow rate to the tower is given by:

$$\dot{m}_l = \alpha.£.c.\sqrt{((\Delta p)/(v2))} \quad (6)$$

Effectiveness of cooling tower:

Effectiveness of cooling tower is given by:

$$\varepsilon = \frac{T_4 - T_5}{T_4 - T_{a1}} \quad (7)$$

Mass flow ratio:

It is the ratio of water mass flow rate to the air mass flow rate:

$$\dot{m}_R = \frac{\dot{m}_w}{\dot{m}_l} \quad (8)$$

3. Experiment Setup and Procedure

The test facility is photographically shown in figure (2) and schematically in figure (3). The tested cooling tower is a forced draft counter flow type. The main part of the installation is the cooling tower, having 1m in height and 0.3 m × 0.3 m in cross section. Water is transported by pump through flow regulated valve. The water flow rate is measured by flow meter and distributed through spray nozzles. Water is distributed in the form of falling films over the extended surfaces (fins). The water distribution system consists of one nozzle having diameter of 2 mm. By using this system water is directly distributed over the fins. The pressure drop at fill zone is measured by digital display manometer.

Sensors were used to measure water inlet and outlet temperature and measure the water temperature in fill zone area. A regulated water flow meter was used to measure amount of water circulated through the system and changed manually by using regulating valves. Also another's sensors were used to measure inlet air temperature, relative humidity and outlet air temperature, relative humidity; all sensors were connected to a digital display. A forced draught fan was used to provide air flow to the tower. The air enters into tower, passes the rain zone, fill zone, spray zone and leaves the tower. The thermal load was modeled with an electric heater located at a water tank. Tower inlet water temperature was controlled by varying heating power. Air flow rate was also controlled by varying and adjusting throttle valve, which allowed changing air flow rate. The tests were conducted at thermodynamics laboratory of mechanical and energy engineering department/ Erbil polytechnic university. The following table shows system technical data:

Table 1. An example of a table

	Equipment	Features
1	Heater	adjustable in three stages: 500-1000-1500 W
2	Thermostat	switches off at 50°C
3	Fan	power consumption: 250 W max. pressure difference: 430 Pa max. volumetric flow rate: 13 m³/min
4	Pump	max. head: 70 m max. flow rate: 100 L/h
5	Tank for additional water	4,2L
6	differential pressure (air)	from 0 to 1000 Pa
7	flow rate (water):	from12 to 360 L/h
8	Volumetric air flow measurement via orifice	D=80mm
9	Extended surfaces (fins)	With angles 30, 50 and 70
10	Cooling column	With dimensions 0.3 m × 0.3 m × 1 m

Tower manufacturers fabricate towers and tower components from a variety of materials. Galvanized steel, various grades of stainless steel, glass fibre, and concrete are widely used in tower construction as well as aluminium and various types of plastics for some components.The inlet air louvers may be glass fibre, the fill may be plastic, and the cold water basin may be steel. Larger towers sometimes are made of concrete. Many towers casings and basins–are constructed of galvanized steel or, where a corrosive atmosphere is a problem, stainless steel. Sometimes a galvanized tower has a stainless steel basin. Glass fibre is also widely used for cooling tower casings and basins, giving long life and protection from the harmful effects of many chemicals. Plastics are widely used for fill, including PVC, polypropylene, and other polymers. Treated wood splash fill is still specified for wood towers, but plastic splash fill is also widely used when water conditions mandate the use of splash fill. Film fill, because it offers greater heat transfer efficiency, is the fill of choice for applications where the circulating water is generally free of debris that could plug the fill passageways. Plastics also find wide use as nozzle materials. Many nozzles are being made of PVC, ABS, polypropylene, and glass-filled nylon. Aluminum, glass fiber, and hot-dipped galvanized steel are commonly used fan materials. Centrifugal fans are often fabricated from galvanized steel [12].

4. Results and Discussion

The variation of the cooling range with water mass flow rate and air mass flow rate are shown in figures (4) and (5), respectively. It is obvious from these figures that the cooling range is decreased with increasing water mass flow rate and increased with increasing air mass flow rate, due to as the amount of heat transfer depends on the two mass flow rates, in case of larger quantity of air that in contact with less quantity of water the results are larger degree of water cooling then cooling range increased, but in case of larger quantity of water that in contact with less quantity of air the results are lesser degree of water cooling then cooling range decreased, for both cases the cooling range increased with increasing fins angles, and the best cooling range was obtained for 70 degree fins angles.

Figures (6) and (7) illustrate the variation of the approach with water mass flow rate and air mass flow rate, respectively. It is obvious from these figures that the approach is increased with increasing water mass flow rate and decreased with increasing air mass flow rate, for the best performance the water should be cooled to the entering air wet bulb temperature.

A decrease in air wet bulb temperature reduces the outlet water temperature. Also, for both cases the approach increased with decreasing fins angles, and the minimum approach was obtained for 70 degree fins angles.

Cooling coefficient will decrease if the water mass flow rate increased and cooling coefficient increased when the air mass flow rate is increased, as shown in figures (8) and (9). As the cooling range is decreased with increasing water mass flow rate and increased with increasing air mass flow rate, which means cooling coefficient directly proportional with a cooling range. Also for both cases the cooling coefficient increased with increasing fins angles, and the best cooling coefficient was obtained for 70 degree fins angles.

Cooling tower effectiveness (in percentage) is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words it is the ratio of range to the range plus approach, the effectiveness is decreased with increasing water mass flow rate and increased with increasing air mass flow rate, as shown in figures (10) and (11). This is because of changing range and approach with both water and air mass flow rates. Also for both cases the cooling tower effectiveness increased with increasing fins angles, and the best cooling tower effectiveness was obtained for 70 degree fins angles.

The performance heat load is determined by the flow rate, and the range of cooling, from figures (12) and (13) it is obvious that the heat load increased with increasing both the water mass flow rate and the air mass flow rate, but the larger increasing that occurred was with increasing air mass flow rate, for example at fins angles 70 heat load starts at 1.3 and ends at 1.5 from figure (13), in the other hand from figure (12) at same fins angles 70 heat load starts at 0.4 and ends at 1.4. Also for both cases the heat load increased with increasing fins angles, and the best heat load was obtained for 70 degree fins angles.

The variation of the change in air relative humidity with water mass flow rate and air mass flow rate are shown in figures (14) and (15), respectively. It is obvious from these figures that the change in air relative humidity is increased with increasing water mass flow rate and decreased with increasing air mass flow rate, this is because evaporating of amount of water during heat transfer process and in case of increasing water mass flow rate the outlet relative humidity absorbs amount of water vapor and then increased making larger humidity difference, but in case of larger air mass flow and lesser water flow the process is reverse. For both cases the change in air relative humidity increased with increasing fins angles, and the larger change in air relative humidity was obtained for 70 degree fins angles.

The performance of a cooling tower depends on the range of cooling, approach, and the mass flow ratio. The mass flow ratio is ratios of water mass flow rate to the air mass flow rate, the outlet water temperature variation is a function of mass flow ratio and different inlet air wet bulb temperature, from the experimental study cooling range is higher in the lower mass flow ratio and it was decreased drastically with increasing the mass flow ratio. In lower mass flow ratio, larger quantity of air was in contact with less quantity of water. But in higher mass flow ratio, the quantities air and water are reverse. So the better cooling range was achieved at lower mass flow ratio as shown in figure (16). Again for this case the cooling range increased with increasing fins angles, and the best cooling range was obtained for 70 degree fins angles.

Figure (17) illustrate the variation of the approach with mass flow ratio. It is obvious from the figure that the approach is increased with increasing mass flow ratio, as for evaporative processes, the difference between the cold water temperature and entering wet bulb temperatures is the approach as mentioned before, also increasing mass flow ratio it means increasing water mass flow rate, which causes increasing approach. The approach increased with decreasing fins angles, the minimum approach was obtained for 70 degree fins angles and the maximum approach was obtained for 30 degree fins angles.

The variation of the cooling tower effectiveness with mass flow ratio is shown in figure (18), as increasing mass flow ratio means increasing water mass flow rate, which causes decreasing effectiveness, because effectiveness decreased with increasing water mass flow rate as mentioned above. Also the cooling tower effectiveness increased with increasing fins angles, and the best cooling tower effectiveness was obtained for 70 degree fins angles.

5. Conclusions

1- It was found that the heat load and heat transfer coefficients are influenced by the mass flow ratio, inlet water temperature, inlet dry bulb air temperature and fins angles. From the experimental study the efficiency of the cooling tower and cooling tower characteristics are higher in case of low mass flow ratio due to higher contact area of water to air. Because of better contact area between airs to water the drop in performance of the cooling tower is less. At higher mass flow ratio, the cooling tower performance was decreased drastically due to large quantity of water and lesser quantity of air. For that reason the contact area between airs to water is in improper ratio. The optimum fins angle obtained from this experimental work was 70 degree, at this angle all cooling tower performance has been calculated were better.

2- Cooling tower's cooling range, cooling coefficient and effectiveness decreased with increasing water mass flow rates and increased with increasing air mass flow rates. Cooling tower's approach increased with increasing water mass flow rates and decreased with increasing air mass flow rates. Cooling tower heat load increased with increasing both water and air mass flow rates. Higher change in relative humidity was obtained at high water mass flow rate and lower change in relative humidity was obtained at high air mass flow rate. Higher tower's cooling range was achieved in the low mass flow ratio. Higher coling tower approach was achieved in the high massflow ratio. Higher cooling tower effectiveness was achieved in the low mass flow ratio.

Nomenclature

a	Approach, oC
c	Constant (= 7.3 X 10-3 [m2])
cpw	Specific heat of water (= 4.18 kJ/kg.K)
$\dot{m}_l$	Air mass flow rate, kg/ Mass flow ratio
M_w	Water loss, kg/s
$\dot{m}_w$	Water mass flow rate, kg/s
Δp	Air pressure difference through the tower, [N/m2]
Qw	Heat load, kW Qw Warm water temperature at the cooling

T4	Warm water temperature at the cooling tower inlet, oC
T5	Cold water temperature at the cooling tower outlet, oC
Ta1	Inlet air dry bulb temperature, oC
Tf1	Wet bulb temperature at tower inlet, oC
v2	Air specific volume at tower outlet, (m3/kg)
X2	Humidity ratio at tower outlet, kgwater / kgdry air
X1	Humidity ratio at tower inlet, kgwater / kgdry air
Z	Cooling range, oC
μ	Cooling coefficient, %
α	Air flow coefficient (= 0.605)
£	Expansion coefficient (= 0.98)

Appendix

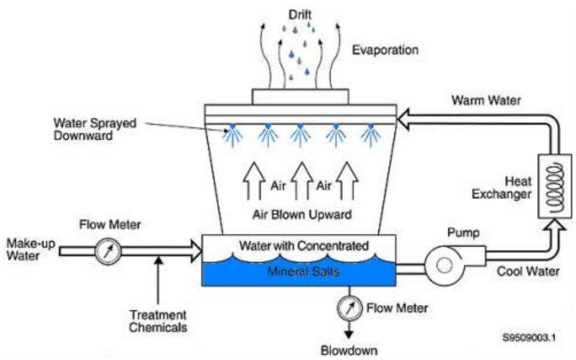

Figure (1): Mechanical drift wet cooling tower

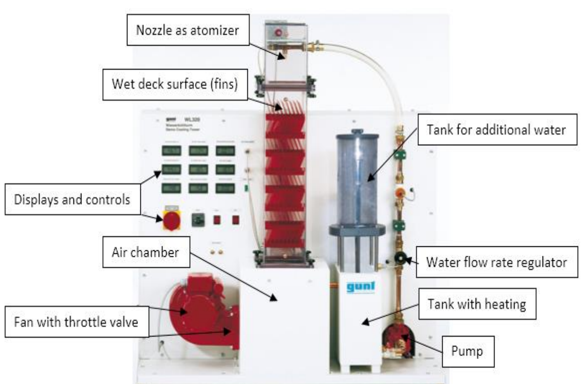

Figure (2): Photograph of the experimental rig.

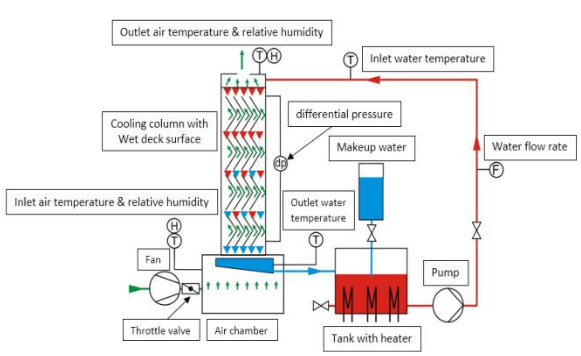

Figure (3): Schematic diagram of the experimental rig and measurements tools positions

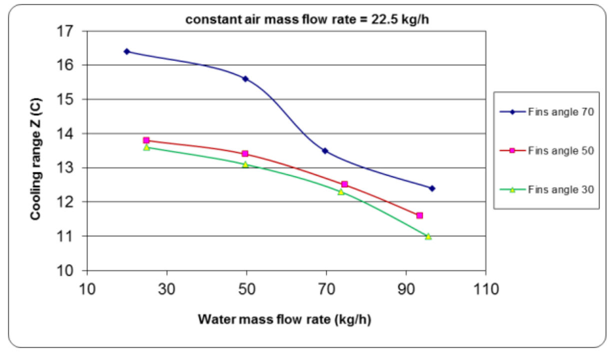

Figure (4): Water mass flow rate versus cooling range

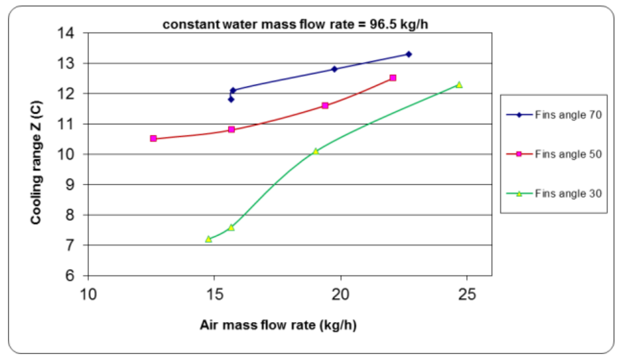

Figure (5): Air mass flow rate versus cooling range

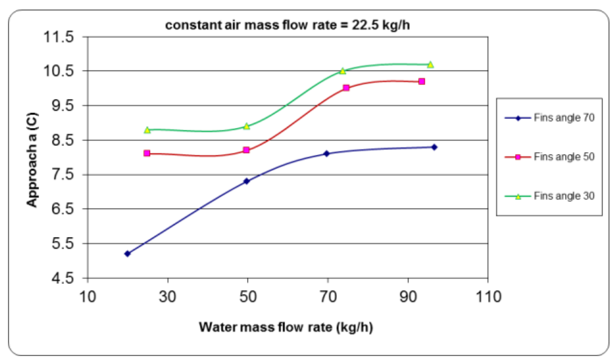

Figure (6): Water mass flow rate versus Approach

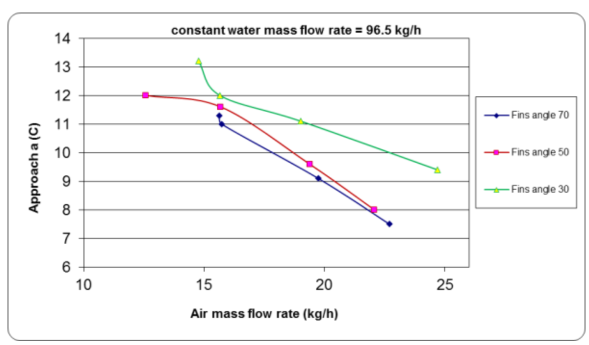

Figure (7): Air mass flow rate versus Approach

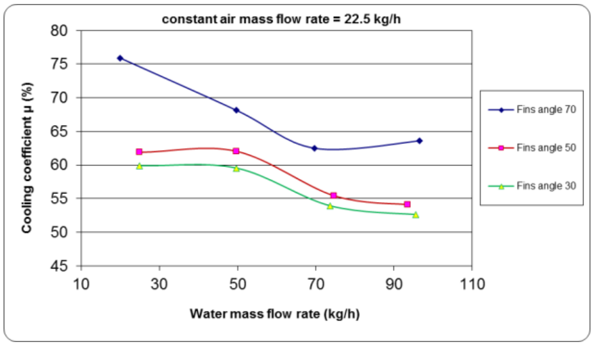

Figure (8): Water mass flow rate versus cooling coefficient

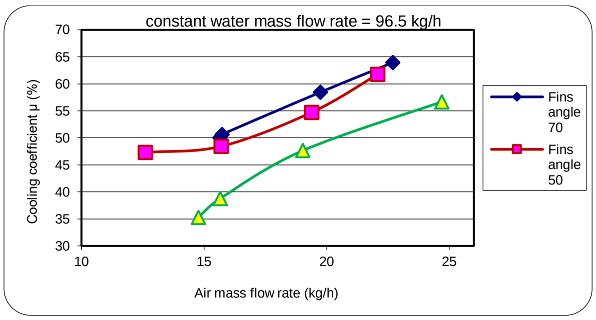

Figure (9): Air mass flow rate versus cooling coefficient

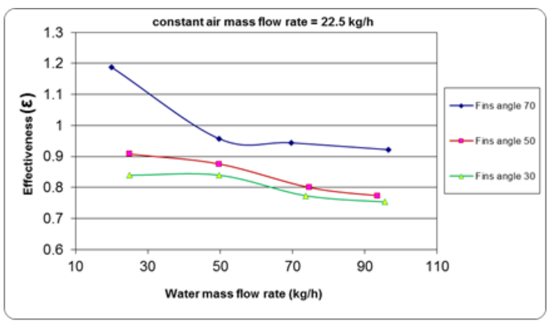

Figure (10): Water mass flow rate versus effectiveness

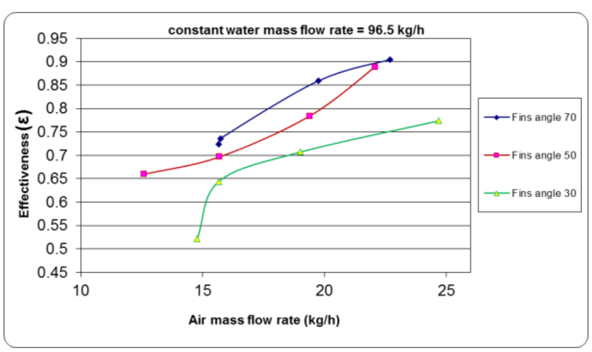

Figure (11): Air mass flow rate versus effectiveness

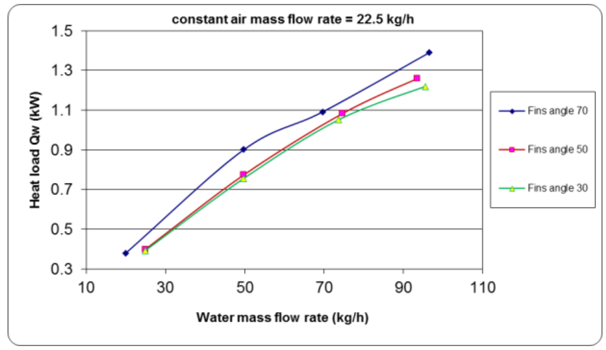

Figure (12): Water mass flow rate versus heat load

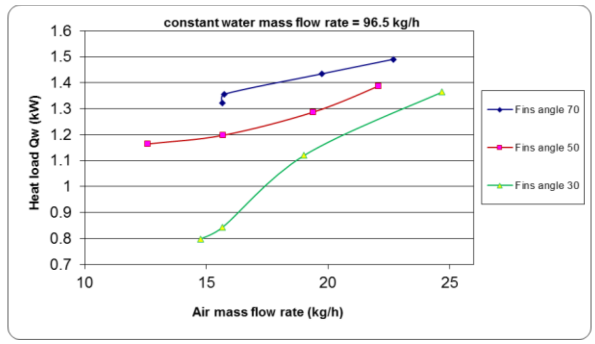

Figure (13): Air mass flow rate versus heat load

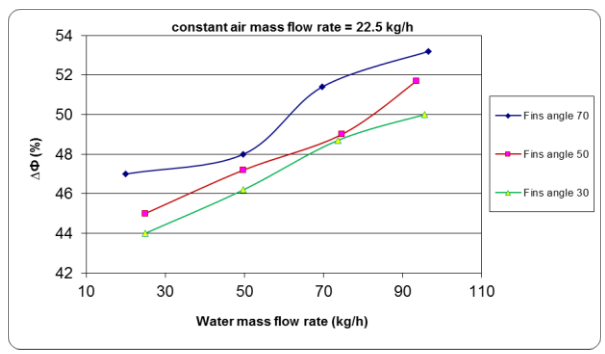

Figure (14): Water mass flow rate versus change in air relative humidity

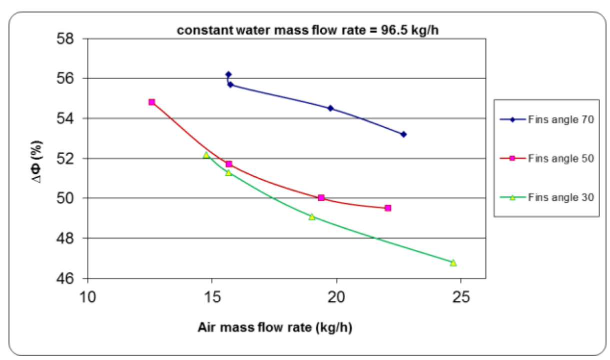

Figure (15): Air mass flow rate versus change in air relative humidity

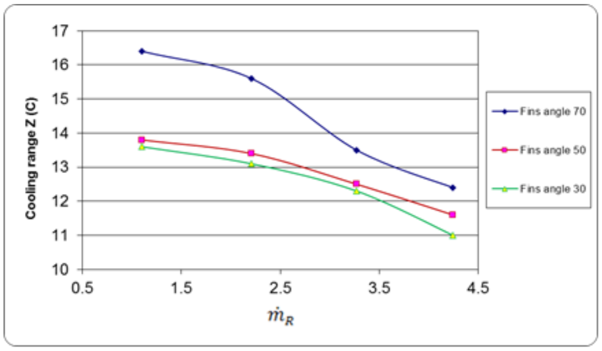

Figure (16): Mass flow ratio versus cooling range

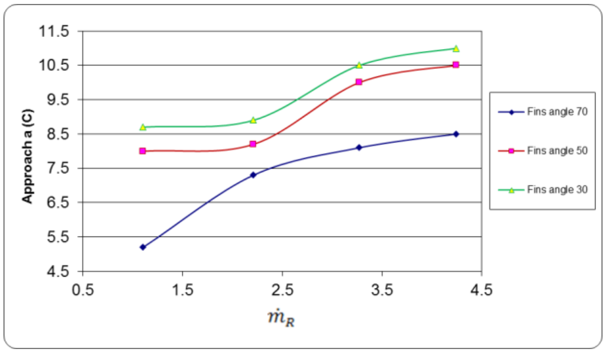

Figure (17): Mass flow ratio versus Approach

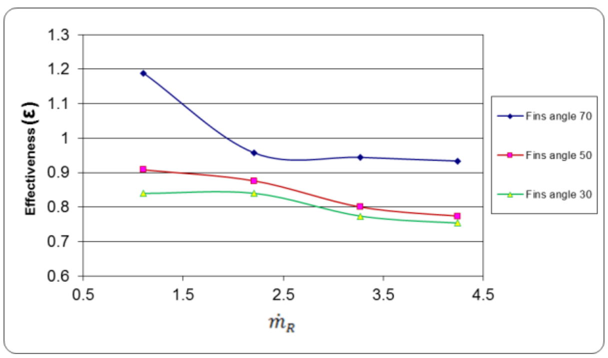

Figure (18): Mass flow ratio versus Effectiveness

References

[1] R. Ramkumar A. Ragupathy, "Thermal performance of forced draft counter flow wet cooling tower with expanded wire mesh packing", International Journal on "Technical and Physical Problems of Engineering" (IJTPE), March 2011, Issue 6, Volume 3, Number 1, pp 19-23.

[2] J.C. Kloppers, D.G. Kroger, "Loss coefficient correlation for wet cooling tower fills", Appl. Therm. Eng., 23 (2003) 2201–2211.

[3] J.R. Khan, B.A. Qureshi, S.M. Zubair, "A comprehensive design and performance evaluation study of counter flow wet cooling towers", Int. J. Refrig., 27 (2004) 914–923.

[4] J.C. Kloppers, D.G. Kroger, "A critical investigation into the heat and mass transfer analysis of counter flow wet-cooling towers", Int. J. Heat Mass Transf., 48 (2005) 765–777.

[5] M. Lemouari, Experimental study of the air/water heat transfer by direct contact in a column packed with vertical grids- application to the water cooling, MSc. Thesis, University of Bejaia, Algeria, 2001.

[6] M. Lemouari, M. Boumaza, "Experimental study of the air/water heat transfer by direct contact in a column packed with vertical grids application to the water cooling", pp. 457–464 in Proceeding 11th International Meeting on Heat Transfer JITH2003. France, 2003.

[7] M. Lemouari, M. Boumaza, "An experimental investigation of thermal characteristics of a mechanical draft wet cooling tower", pp. 111–120 in Proceedings 13th IAHR, Poitiers, France, 2005.

[8] F. Jorge, C.O. Armando, "Thermal behavior of closed wet cooling towers for use with chilled ceilings", Appl. Therm. Eng., 20 (2000) 1225–1236.

[9] P. Naphon, "Study on the heat transfer characteristics of an evaporative cooling tower", Int. Comm. Heat Mass Transf., 32 (2005) 1066–1074.

[10] E. Elsarrag, "Experimental study and predictions of an inclined draft ceramic tile packing cooling tower", Energ. Convers. Manage. 47 (2006) 2034–2043.

[11] Dr. Najim A. Jassim, "THEORETICAL AND EXPERIMENTAL STUDY ON THERMAL PERFORMANCE OF CLOSED WET COOLING TOWER", Department of Mechanical Engineering, College of Engineering, University of Baghdad, Iraq, Number 6, Volume 17, December 2011, Journal of Engineering.

[12] Krishna S. Vishwakarma, Arpit S. Bhoyar, Saahil K. Larokar,Vaibhav V. Hote,Saurabh Bhudhbaware, "Study the factors on which efficiency of cooling tower can be critically acclaimed (A case Study)", K S. Vishwakarma et al. Int. Journal of Engineering Research and Applications. ISSN: 2248-9622, Vol. 5, Issue 4, (Part -3) April 2015, pp.73-79