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Experimental Study of the parameters Affect on the Thermal Performance of Cooling Tower

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ABSTRACT

Cooling tower is a type of direct contact heat exchanger, inside of which heat is withdrawn from water to air. In this research experimental study of the performance of forced draft counter flow cooling tower at different conditions and different operating parameters. The study was conducted for different water inlet temperature, different water flow rate, different air flow rate, different injection holes diameter, different interval distance between injection holes and different types of packing. The results obtained indicate an increase cooling tower efficiency with the increase of water inlet temperature, air flow rate, interval distance between injection holes while it is decreased with the increase of injection holes diameter and water flow rate. The packing of metal mesh has highest efficiency. The efficiency of cooling tower with metal packing is higher than that with plastic cells by 5.6%, with that of Kraft paper by 40.4% and with the case of no packing by 51.8 %. However, the packing metal mesh is highest in pressure drop of other the types.

ملخص البحث:

برج التبريد هو نوع من المبادلات الحرارية المباشرة، حيث يتم سحب الحرارة من الماء إلى الهواء. في هذا البحث دراسة عملية لأداء برج تبريد ذو التدفق المتعاكس في ظروف مختلفة ومعلمات تشغيل مختلفة. وأجريت الدراسة لمختلف درجات حرارة مدخل المياه ومعدل تدفق الماء المختلفة ومعدل تدفق الهواء المختلفة وقطر الثقوب المختلفة للحقن والمسافة البينية بين ثقوب الحقن وأنواع التعبئة المختلفة. تشير النتائج التي تم الحصول عليها إلى زيادة كفاءة برج التبريد مع زيادة درجة حرارة مدخل المياه ومعدل تدفق الهواء والمسافة البينية بين ثقوب الحقن في حين انخفض مع زيادة قطر فتحات الحقن ومعدل تدفق المياه. وقد بينت النتائج ان كفاءة برج التبريد تزداد في حالة الحشو بشبكة سلك معدني أعلي من الحالات الأخري، فهي أعلي من حالة الحشو بالخلايا البلاستيكية بمقدار 5.6%، وأعلي من ورق الكرافت بمقدار 40.4% وأعلي من حالة عدم وجود حشو بمقدار 51.8%. ومع ذلك فإن استخدام الشبكة المعدنية يؤدي إلي انخفاض في الضغط أكبر من الحالات الأخري.

Keywords: Cooling Tower, Direct contact heat exchanger.

1- INTRODUCTION

Cooling tower is a device that used to reduce the temperature of hot water stream by extracting heat from it by direct contact with air. It also makes use of evaporation whereby some of the water is evaporated into a moving air stream and subsequently discharged into the atmosphere. As a result, the remainder of the water is cooled down significantly. Cooling towers are able to decrease the water temperatures more than devices that use only air to reject heat, like the radiator in a car, therefore more cost-effective and energy efficient.

Numerous studies have been conducted on the cooling towers in order to investigate water temperature range, cooling tower efficiency, vaporization rate, etc. Nahavandi et al. [1] studied, theoretically, the effect evaporation losses in the analysis of counter flow cooling towers. They developed a technique for solving cooling tower thermal design problems. That method included the evaporation losses in the analysis, and was compared with Merkel solution [2], which ignored the evaporation losses. The comparison showed that, ignoring the evaporation losses introduced an error in the Merkel results which were not conservative and may reach 12% depending on design conditions.

El-Desouky [3] used spongy rubber balls of 12.7 mm diameter and 375 kg/m^3 density to study experimentally the thermal and hydraulic characteristics of a three-phase fluidized bed cooling tower. The air-side pressure drop and the minimum fluidization velocity were measured. The water/air mass flux ratio was ranged between (0.4-2) and hot water inlet temperature was (28-61 °C).

The effect of form with corrugated packing on mass transfer and pressure drop characteristics in atmospheric cooling towers was studied experimentally by Goshayshi and Missenden [4]. It was found that the overall mass transfer coefficients and pressure drops of ribbed corrugated packing increase considerably compared with smooth packing and affected by spacing of the packing and the distance between the ribs. Abdel-Ghaffar [5] studied the effect of operating parameters on the performance of counter flow cooling tower. The study was conducted on three types of film fill packing, and involves the effect of air velocity and water to air flow rate on the performance of counter flow cooling tower. An experimental investigation of thermal characteristics of a mechanical draft wet cooling tower was studied by Lemouari et al [6-8]. They Studied the effect of the air and water flow rate on the cooling water range as well as the tower characteristic.

Naphon [9] studied experimentally and theoretically the effect of air and water mass flow rates as well as water inlet temperature on outlet air and water temperatures, heat transfer and cooling tower efficiency. The mathematical model was solved by the iterative method. Reasonable agreement was obtained from the comparison between the results obtained from the experiment and those obtained from the model. The effect of water to air flow ratio on the performance and mass transfer coefficient of the mechanical cooling tower was studied experimentally by Gharagheizi et al. [10]. The study was conducted on two film type packing, vertical corrugated packing and horizontal corrugated packing. They indicated from the results that the performance of the cooling tower was affected by the type and arrangement of the packing.

Goshayshi and Missenden [11] studied experimentally the thermal performance of cooling tower used fluidized bed as a packing material. They studied the effect the thermal performance, packed density and velocity of a fluidized bed on performance cooling tower. They showed the effect thermal performance on the cooling tower characteristic, of the different packing elements and of varying water flow rate, air flow rate and the height of the hot water distributor above the bed. Mahmoud et al. [12] studied the thermal performance of counter flow cooling tower with three different types of packing; corrugated plastic sheets, perforated aluminum square channel sheets and plastic balls arranged in square matrix. The performance was analyzed theoretically and experimentally through studying the effect of hot water entering temperature with different mass flow rate of water and air for the three types of packing.

Kara [13] studied experimentally the thermal performances of a forced draft counter flow wet cooling tower with the packing of laminated plastic plates. He studied the effect of the air and water mass flow rate ranging between 0.017 and 0.064 kg/s for air and between 0.03 and 0.05 kg/s for water. The inlet air wet bulb temperature at 23 °C, and water inlet temperatures are between 38 and 47 °C.

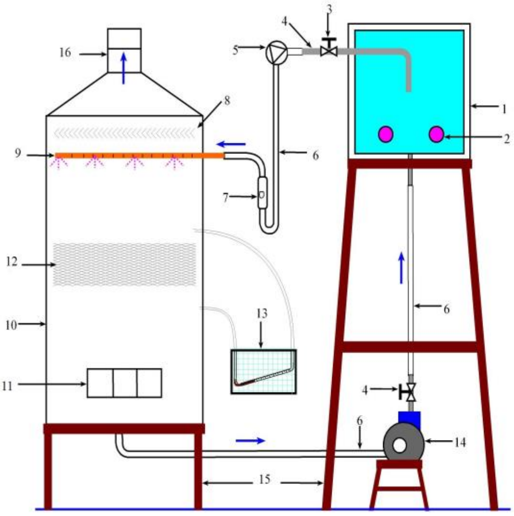
Khorshidi et al [14] studied experimentally and theoretically the effect of parameters of three packing's in types of vertical corrugated, horizontal corrugated and mixed corrugated on the performance of cooling tower. Lavasani et al. [15] studied experimentally the performance of a forced draft counter flow wet cooling tower filled with the packing of horizontal wooden slats. They studied the effect of rotational packing and compared the result with the non-rotational packing. The investigation was carried out for three inlet air temperatures 27, 34 and 41 °C while water temperature is kept constant at 45 °C. Experimental investigation on the effect of fill materials in cooling towers on its performance was studied by Jayaprabakar [16]. The performance of the cooling tower was evaluated using spherical balls, wood ribbon and fiber reinforced plastics. Patel and Mohite [17] studied the effect of twisted tape inside the cooling tower in horizontal position and vertical positions on performance of the cooling tower. Twisted tape made up of 3mm thick and 19mm wide aluminum tape.

Tao et al. [18] studied experimentally the thermal performance of a wet cooling tower filled with film packing under different conditions for a wide range of water/air ratio. They used the plastic sloping corrugated packing. The investigation focused on the effect of inlet water temperatures at 40, 45 C water and air flow rates ranges from 8000 to 14000 kg/h and ranges from 5880 to 36480 kg/h respectively. Performance Analysis of induced forced draft cooling tower was studied by Arunkumar et al. [19]. The effect of the efficiency and the evaporative loss on performance of cooling tower was studied experimentally with and without fill material at inlet water temperatures 45, 50, 55 °C. Shahali et al. [20] studied experimentally the effect of water flow rate, water inlet temperature, air flow rate and type and packing arrangement on cooling tower performance for three different types of PVC packing 7, 9 and 18 ribs. The performance of WCT was evaluated based on variation in the inlet water temperature and different values of water and air mass flow rates. Kong et al [21] studied experimentally the heat and mass transfer phenomena in a counter flow wet cooling tower with foam ceramic packing. The study was focused mainly on the effect of the water–air mass flow ratio on the heat and mass transfer characteristics of the cooling tower, for different inlet water temperatures and different water mass flow rate.

The review of the previous work has no studying the effect of injection holes diameter, interval distance between injection holes using three types of packing, lack packing on each of efficiency, heat rejected and mass transfer. These led us to study the effect of these parameters on the performance of cooling tower.

2- Experimental Study:

The experimental apparatus was designed and constructed as shown with its all details in Fig. 1. Hot water is supplied from a tank of 500×500 ×500 mm. The tank was made of steel of 4 mm thickness and it is fixed on a steel frame stand. The tank is equipped with two electric heating coils of 1.5 kW each. The coils were supplied with thermostat to maintain constant temperature. The hot water was taken from the tank at a high level by a pump of 40 W power. It was passed through a flow meter, which can adjust the flow rate of water. The hot water was injected from the top through injection tube, the water was distributed equally and sprayed in the form of drops to the basin after passing through a packing. Three kinds of packing were chosen to compare between them, they were: Kraft paper, Plastic cell and metal wire mesh. The hot water was returned to the tank by a centrifugal pump of 0.37 kW power. Drift eliminator was installed at the outlet of the air to prevent any droplet water to come out with air and returns it back to the basin.



1- Isolated hot water tank. 2- Electric heart.
3- Control valve. 4- Steel tube.
5- Water circulation pump. 6- Rubber tube.
7- Flow-meter. 8- Eliminator.
9- Water injection tube. 10- Tower.
11- Inlet air fan connection 12- Packing.
13- Manometer. 14- Pump.
15- Stand Frame. 16- Exhaust air duct.

Fig. (1). Experimental apparatus details

The required flow rate was adjusted by the aid of a valve and a Rota meter. The front and back sides of the outer case of the heat exchanger were made of acrylic while the two sides were made of steel. An air blower was installed at the bottom of front side for supplying the required air.

Sixteen models of water injection tube were chosen. Each of them was made of PVC tube of with inner and outer diameters of 25.4 and 26.6 mm respectively. Four models of the tubes were chosen at 25 mm apart between injection holes, four was at 50 mm apart, four was at 75 mm apart and the last four was at 100 mm apart. Four different injection diameters 1, 2, 3 and 4 mm was chosen for each four models. Table (1) indicates a summary of the sixteen models.

Table (1): Summary of the injection models

Distance	Injection hole diameters, [mm]			
	d_1	d_2	d_3	d_4
25 mm apart	1	2	3	4
50 mm apart				
75 mm apart				
100 mm apart				

The temperature of hot water was measured at the inlet and outlet of each coil with the aid of calibrated copper constantan thermocouples. The output of the thermocouples was read by calibrated digital indicator. The error of measuring was 0.029%. The inlet and outlet temperature and relative humidity of air were measured by two calibrated humidifiers with error 0.022%. The air velocity was measured at air outlet by the aid of portable anemometer with error 0.05%.

3- Results and Discussions:

The performance of the cooling tower is affected by many parameters such as; the mass flow rate and inlet temperature for both water and air. These parameters affect each of efficiency, heat rejected and mass transfer of the experimental cooling tower.

3-1 Effect of Water Inlet Temperature:

The effect of water inlet temperature on each of efficiency, heat rejected and mass transfer of the experimental cooling tower was studied at water/air mass flow ratio (MR) of 0.685, 0.8, 0.913, 1.027 and 1.142. This effect was conducted at water inlet temperature of 35, 40, 45, 50 and 55 [°C], injection holes diameter of the water was 2 [mm], the interval distance between the injections of the water was 25 [mm] and the air mass flow rate of 0.073 [kg/s].

The cooling tower efficiency (η) could be calculated as:

$$\eta = \frac{(T_{w,i} - T_{w,o})}{(T_{w,i} - T_{wb1})} \quad (1)$$

The equation indicates that, the cooling tower efficiency depends on the water temperature and wet bulb temperature of the air. Figure (2) shows the effect of water inlet temperature on the cooling tower efficiency for different flow mass rate ratio. The figure indicates that, the cooling tower efficiency increases when the water inlet temperature was increased. As an example, for the case of MR= 0.8, the cooling tower efficiency is increased from 0.192 to 0.241 with a percentage increase of 25.5% when the water inlet temperature is changed from 35 to 55 [°C].

On the other hand, the cooling tower efficiency decreases with the increase of water/air mass flow ratio for all inlet water temperatures. As example for the case of water inlet temperature of 45°C, the effectiveness is decreased from 0.225 to 0.186 with a percentage decrease of 17.3 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%. This could be explained as, for the same heat loss from water, the temperature difference of water is in reverse proportion with the mass flow rate. This in turn leads to decrease the cooling tower efficiency.

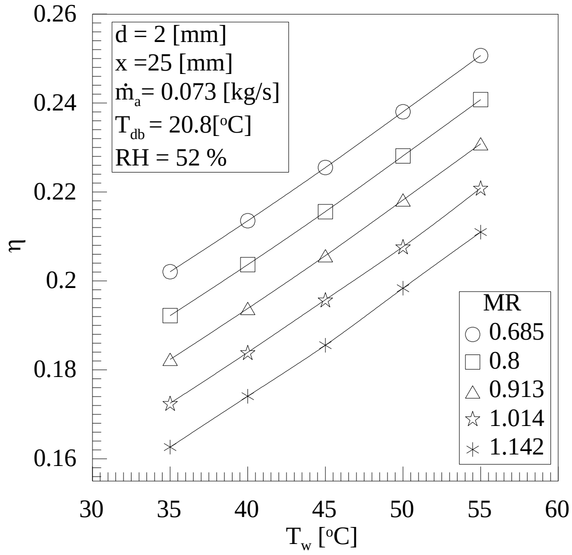


Fig. (2). Effect of water inlet temperature on the effectiveness for different mass flow rate ratio.

The heat rejected $(\dot{Q}_w)$ from the water through the cooling tower could be calculated as indicated in [21] by Eq. (2);

$$\dot{Q}_w = \dot{m}_w Cp_w T_{wi} - (\dot{m}_w - \dot{m}_v) Cp_w T_{wo} \qquad (2)$$

The error in measuring the flow rate is 1.67% and that of calculating the heat rejected is 1.7%. The effect of water inlet temperature on the heat rejected at different mass flow rate ratio is illustrated in Fig. (3). For each case of MR, the increase of water inlet temperature leads to an increase of heat transfer between water and air which reflected on the heat rejected as shown in the figure. For example, for the case of MR = 0.8, the rejected heat is increased from 62 to 129.2 [W] with a percentage increase of 108.4% when the water inlet temperature is changed from 35 to 55 [°C].

The figure indicates also that, the heat rejected from the water increases slightly with the increase of MR for all inlet water temperatures. As example for the case of water inlet temperature of 45 °C, the rejected heat is increased from 90.1 to 102.9 [W] with a percentage increase of 14.2 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%. This is because the increase of water mass flow rate means an increase of the heat capacity of it, which in turn leads to heat rejected.

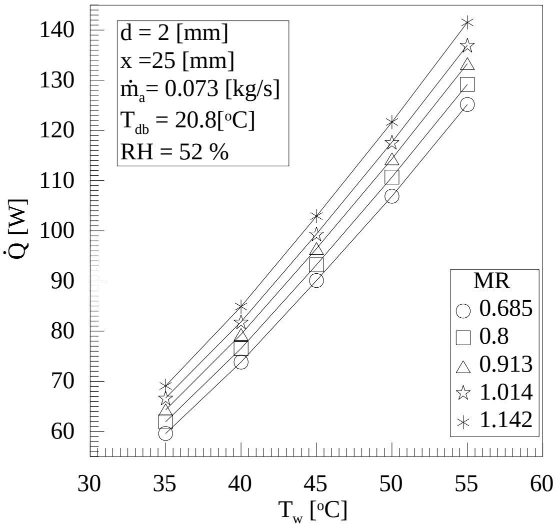


Fig. (3). Effect of water inlet temperature on the rejected heat for different mass flow rate ratio.

The heat transfer in cooling tower occurs between water and air as well as between the droplets of water. Due to heat transfer, some of the sprayed water gains heat which resulting in vaporization of them. Make up water is required instead of this vaporized water. So, the amount of water vapor could be obtained by the following relation:

$$\dot{m}_v = \dot{m}_a (\omega_2 - \omega_1) \qquad (3)$$

$$\dot{m} = \rho A C \qquad (4)$$

Where: ω_1 and ω_2 are the humidity ratio obtained at air inlet and outlet conditions from digital Pyschrometric chart program as shown in Fig. (4) the required values of air properties.

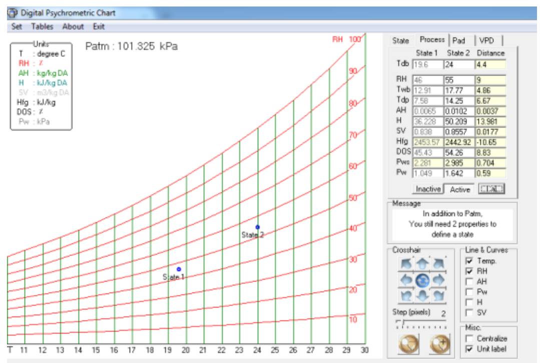


Fig. (4). Digital Pyschrometric chart program

Figure (5) shows the effect of water inlet temperature on the vaporization rate for different flow mass rate ratio. The figure indicates that, for the same water/air mass flow ratio the vaporization rate increases when the inlet water temperature was increased. It is found that for the case of water for the case of MR = 0.8, the vaporization rate is increased from 0.47 to 0.67 [g/s] with a percentage increase of 42.6% when the water inlet temperature is changed from 35 to 55 [°C].

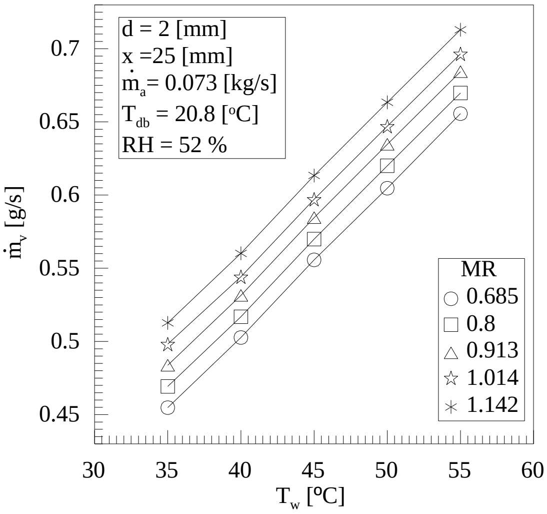


Fig. (5). Effect of water inlet temperature on the vaporization rate for different mass flow rate ratio.

The figure indicates also that, the vaporization rate increases with the increase of water/air mass flow ratio for all inlet water temperatures. As example for the case of water inlet temperature of 45°C, the water vaporization rate is increased from 0.556 to 0.613 [g/s] with a percentage increase of 10.3 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%. On the other hand, the vaporization rate increases with the increase of water inlet temperature as shown in the figure.

3-2 Effect of Water Mass Flow Rate:

The effect of water mass flow rate on each of efficiency, heat rejected and mass transfer of the experimental cooling tower was studied. The chosen flow rates of water were: 3, 3.5, 4, 4.5 and 5 *l*/min. The corresponding mass flow rates were: 0.05, 0.058, 0.067, 0.075 and 0.083 [kg/s]. The effect was conducted at water inlet temperature of 45 [°C], injection holes diameter was 2 [mm] and the interval distance between the injections was 50 [mm].

Figure (6) illustrates the cooling tower efficiency as a function of water mass flow rates for different air mass flow rate. The figure indicates that, the cooling tower efficiency is decreased as the water mass flow rate is increased. As an example, for the case of air mass flow rate of 0.073 [kg/s], the cooling tower efficiency is decreases from 0.231 to 0.179 with a percentage decrease of 22.5% when the water flow rate is changed from 0.05 to 0.083[kg/s] with a percentage increase of 66%.

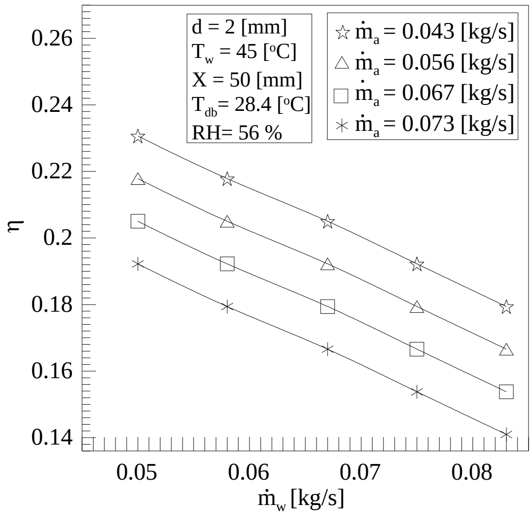


Fig. (6). Effect of water mass flow rate on the cooling tower efficiency for different air mass flow rate.

The figure indicates also that, the cooling tower efficiency increases with the increase of air mass flow rate for all water mass flow rate. As example for the case of water mass flow rate of 0.067 [kg/s], the cooling tower efficiency is increased from 0.167 to 0.205 with a percentage increase of 22.8% when the air mass flow rate is increased from 0.043 to 0.073 [kg/sec] with a percentage increase of 69.77%.

The effect of water mass flow rate on the heat rejected for all mass flow rates of air is illustrated in Fig. (7). The figure indicates that, for the same air mass flow rate, the heat rejected increases when the water mass flow rate was increased. For the case of air mass flow rate of 0.073 [kg/sec], the heat rejected increases from 165 to 184.3 [W] with a percentage increase of 11.7 % when the water mass flow rate is changed from 0.05 to 0.083 [kg/s] with a percentage increase of 66%.

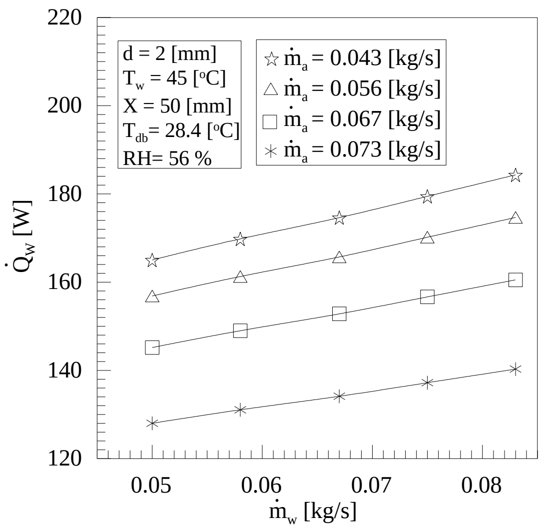


Fig. (7). Effect of water mass flow rate on the heat rejected for different air mass flow rate.

For each value of water mass flow rate, the heat rejected increases with the increase of air mass flow rate for all water mass flow rate. It is found that for the case of water mass flow rate of 0.067 [kg/s], the heat rejected is increased from 134.1 to 174.6 [W] with a percentage increase of 30.2 % when the air mass flow rate is increased from 0.043 to 0.073 [kg/s] with a percentage increase of 69.77%.

Figure (8) indicates the effect of water mass flow rate on the vaporization rate for different air mass flow rate. The figure indicates that, for the same air mass flow rate the vaporization rate increases when the water mass flow rate was increased. For the case of air mass flow rate of 0.073 [kg/s], the vaporization rate increases from 0.99 to 1.072 [g/s] with a percentage increase of 8.3% when the air mass flow rate is changed from 0.05 to 0.083[kg/s] with a percentage increase of 66%**.**

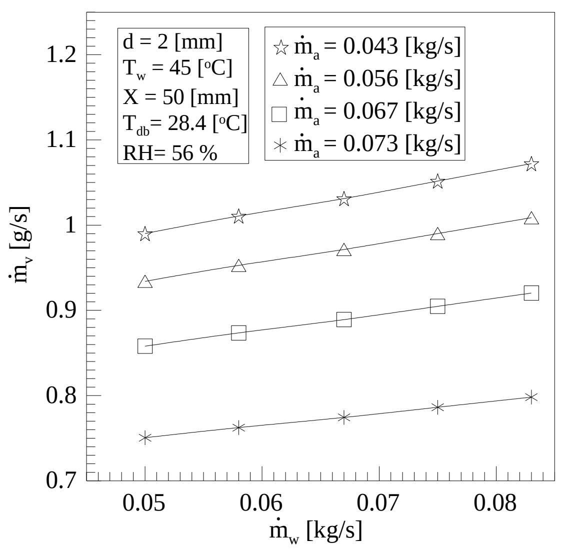


Fig. (8). Effect of water mass flow rate on the vaporization for different air mass flow rate.

For each value of water mass flow rate, the vaporization rate increases with the increase of air mass flow rate for all water mass flow rate. It is found that for the case of water mass flow rate of 0.067 [kg/s], the vaporization rate is increased from 0.774 to 1.031 [g/s] with a percentage increase of 33.2 % when the air mass flow rate is increased from 0.043 to 0.073 [kg/s] with a percentage increase of 69.77%.

3-3 Effect of Injection Holes Diameter:

The effect of injection holes diameter on each of the efficiency, heat rejected and mass transfer of the experimental cooling tower was studied at water/air mass flow ratio of 0.685, 0.8, 0.913, 1.014 and 1.142. This effect was conducted at injection holes diameter of 1, 2, 3 and 4 [mm] at inlet water temperature was 45°C, the interval distance between the injection holes of the water was 25 [mm] and the air mass flow rate of 0.073 [kg/sec].

Figure (9) illustrates the effect of injection holes diameter on the cooling tower efficiency for different mass flow rate ratio. The figure indicates that for the same MR, the cooling tower efficiency decreases when the injection holes diameter was increased. As explained previously, that the temperature difference is decreased when the injection holes diameter is increased, this tends to decrease the cooling tower efficiency. As an example, for the case of MR=0.8, the cooling tower efficiency is decreases from 0.227 to 0.172 with a percentage decrease of 24.2% when the water injection holes diameter is changed from 1 to 4 [mm].

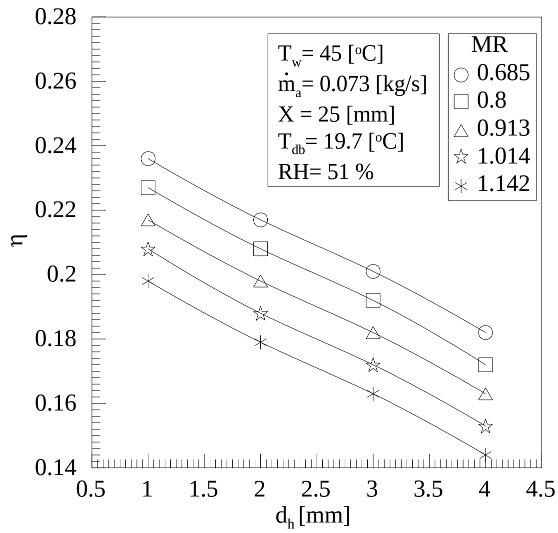


Fig. (9). Effect of injection holes diameter on the cooling tower efficiency for different mass flow rate ratio.

For the same different injection holes diameter, the cooling tower efficiency decreases with the increase of MR for all injection holes diameter. As example for the case of injection holes diameter of 2 [mm], the effectiveness is decreased from 0.217 to 0.179 with a percentage decrease of 17.5 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%. This could be explained as, for the same heat loss from the hot water, the temperature difference of water is in reverse proportion with its mass flow rate. This in turn leads to decrease the cooling tower efficiency.

Figure (10) illustrates the effect of injection holes diameter on the heat rejected for different mass flow rate ratio (MR). The figure indicates that for the same MR, the heat rejected decreases when the injection holes diameter was increased as indicated in the Figure. This may be explained as when the diameter is decreased, the sprayed water has small droplets size which in turn tends to increase the heat transferred between these droplets. Some of droplets gain heat and vaporized while the other lost heat and cooled. For the case of MR = 0.8, the rejected heat is decreased from 94.6 to 90.9 [W] with a percentage decrease of 3.9% when the injection holes diameter is changed from 1 to 4 [mm].

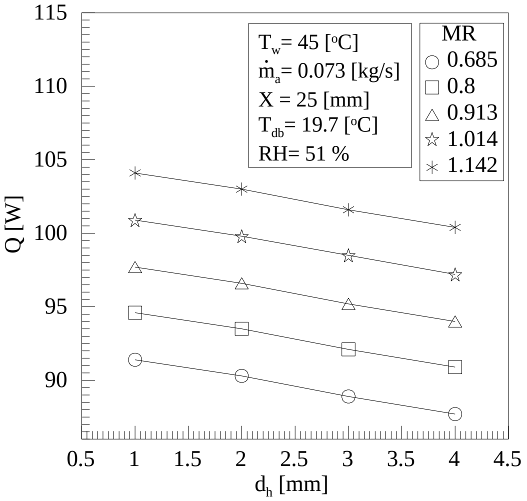


Fig. (10). effect of injection holes diameter on the heat rejected for different mass flow rate ratio.

The figure indicates also that for the same injection holes diameter, the rejected heat increases with the increase of MR for all injection holes diameters. As example for the case of injection holes diameter of 2 mm, the rejected heat is increased from 90.3 to 103 [W] with a percentage increase of 14.1 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%.

As mentioned before, the mass transfer is defined as the rate of vaporized water that carried out by air. Figure (11) indicates the effect of injection holes diameter on the vaporization rate for different mass flow rate ratio (MR). The figure indicates that, the vaporization rate decreases when the different injection holes diameter was increased as indicated by equation (3) and also shown in the figure. This is because the decrease of injection holes diameters result in small sizes of droplet. Consequently, the rate of vaporization increases as mentioned previously. As an example, for the case of MR = 0.8, the vaporization rate is decreased from 0.586 to 0.541 [g/s] with a percentage increase of 7.7% when the injection holes diameter is changed from 1 to 4 [mm].

For different injection holes diameter, the vaporization rate increases with the increase of water/air mass flow ratio for all injection holes diameters. It is found that, for the case of injection holes diameter of 2 [mm], the vaporization rate is increased from 0.557 to 0.614 [g/s] with a percentage increase of 10.2 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%.

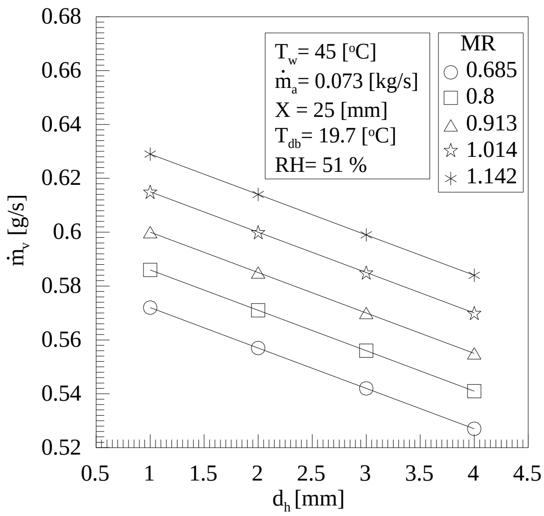


Fig. (11). Effect of injection holes diameter on the vaporization rate for different mass flow rate ratio.

3.4 Effect of the Interval Distance between Injection Holes:

The effect of the interval distance between the injection holes on each of cooling tower efficiency, heat rejected and mass transfer was studied at water/air mass flow ratio 0.685, 0.8, 0.913, 1.014 and 1.142. This effect was conducted at distance between injection holes of 25, 50, 75 and 100 [mm] and inlet water temperature 45 °C, the interval injection holes diameter of the water was 2 [mm] and the air mass flow rate of 0.073 [kg/s].

Figure (12) shows the effect of interval distance between injection holes on the cooling tower efficiency for different mass flow rate ratio (MR). The figure indicates that for each mass flow rate ratio, the cooling tower efficiency increases when the injection holes diameter was increased. As an example, for the case of MR = 0.8, the cooling tower efficiency is increases from 0.169 to 0.198 with a percentage increase of 17.2% when the water distance between injection holes is changed from 25 to 100 [mm].

For the same interval distance between injection holes, the water temperature difference decreases with the increase of MR. As example for the case of distance between injection holes of 50 [mm], the water temperature difference is decreased from 5.9 to 5 °C with a percentage decrease of 15.3 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%. This can be explained as the increase of mass flow rate ratio means an increase of the water mass flow rate which results in a decrease of its temperature difference for the same heat loss.

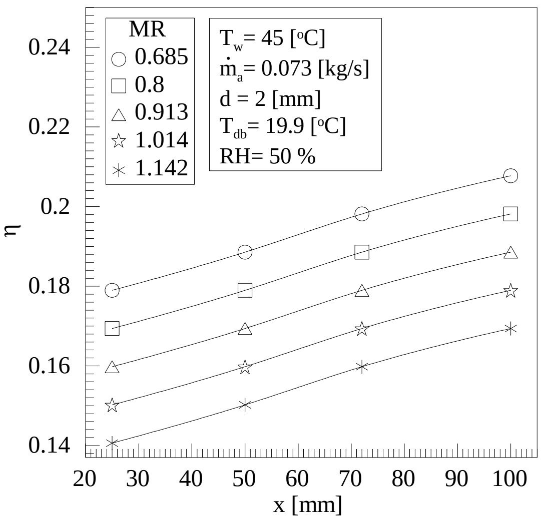


Fig. (12). Effect of interval distance between injection holes on the cooling tower efficiency for different mass flow rate ratio.

Figure (13) illustrates the effect of interval distance between injection holes on the rejected heat for different mass flow rate ratio (MR). The figure indicates that for each mass flow rate ratio, the rejected heat increases when different distance between injection holes was increased as indicated by equation (2) and also shown in the figure. As an example, for the case of MR = 0.8, the rejected heat is increased from 82.6 to 94.2 [W] with a percentage increase of 14% when the distance between injection holes is changed from 25 to 100 [mm].

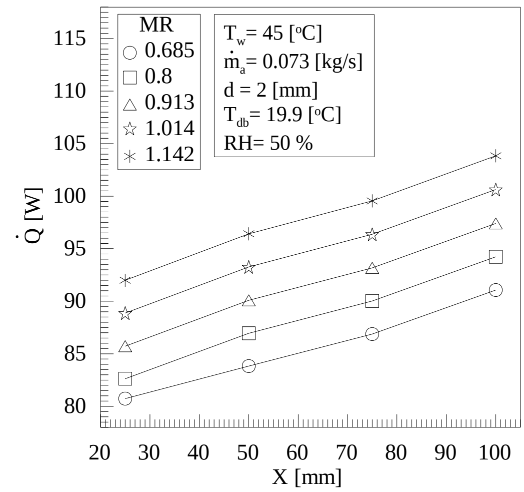


Fig. (13). Effect of interval distance between injection holes on the rejected heat for different mass flow rate ratio.

The figure indicates also that, the rejected heat increases with the increase of water/air mass flow ratio for all interval distance between injection holes. As example for the case of interval distance between injection holes of 50 [mm], the rejected heat is increased from 83.8 to 94.4 [W] with a percentage increase of 12.6% when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%.

Figure (14) indicates the effect of interval distance between injection holes on the vaporization rate for different mass flow rate ratio (MR). The figure indicates that, the water vaporization rate increases when different interval distance between injection holes was increased. As an example, for the case MR = 0.8, the vaporization rate is increased from 0.490 to 0.572 [g/s] with a percentage increase of 16.7% when distance between injection holes is changed from 25 to 100 [mm].

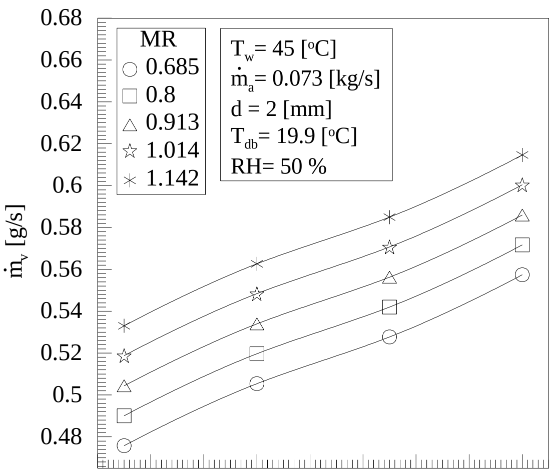


Fig. (14). Effect of interval distance between injection holes on the vaporization rate for different mass flow rate ratio

For each interval distance between injection holes, the vaporization rate increases with the increase of mass flow rate ratio for all injection holes diameters. As example for the case of the interval distance between injection holes of 50 [mm], the vaporization rate is increased from 0.505 to 0.563 [g/s] with a percentage increase of 11.5 % when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%.

3.5 Effect of Packing:

The previous studies were conducted on cooling tower without Packing. Now the study of the examined parameters has been conducted on the cooling tower with packing. The aim of this study is to examine the performance of the cooling tower with and without packing. The study was conducted for different types of packing; those are: kraft paper, plastic cell and galvanized iron wire mesh. The results obtained was compared with the case of no packing. The parameters studied were efficiency, heat rejected, mass transfer and pressure drop of the experimental cooling tower. The studies were obtained at water/air mass flow ratio of 0.685, 0.8, 0.913, 1.014 and 1.142. The inlet hot water temperature was 45°C, injection holes diameter was 2 [mm], interval distance between the injections of the water was 50 [mm] and the air mass flow rate of 0.073 [kg/s].

Figure (15) illustrates the cooling tower efficiency versus water/air mass flow ratio (MR) with and without packing. The figure indicates that for each value of MR, the cooling tower efficiency for metal wire mesh has the highest value followed by plastic cell efficiency has the lowest value for empty cooling tower. This may be explained as the contact area between the packing and the water is considerably large for metal wire mesh packing which tends to more heat transfer and consequently the cooling tower efficiency increases.

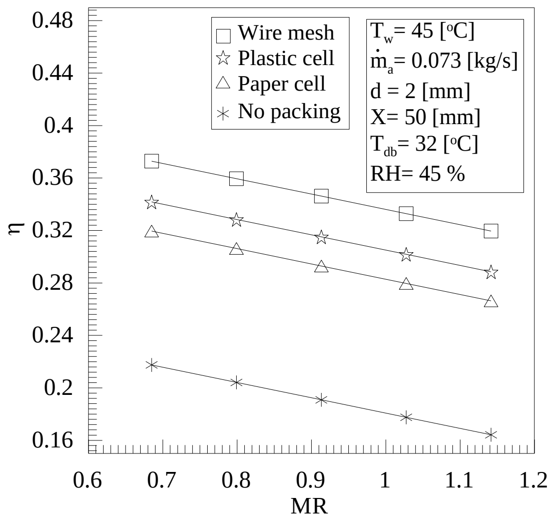


Fig. (15). Cooling tower efficiency versus water/air mass flow ratio (MR) with and without packing

Besides the heat transfer characteristics is the best for metal compared to plastic cells or kraft paper cells. It can be seen also from the figure that, the cooling tower efficiency decreases gradually with the increase of MR for all types of packing. The attained percentage decrease in efficiency for metal mesh is 14.3%, for plastic cells is 15.6%, for Kraft paper is 16.7% while for no packing the percentage decrease reaches 24.5%.

Figure (16) illustrates the rejected heat versus water/air flow ratio MR with and without packing. The figure indicates that, the rejected heat increases with the increase of water/air mass flow ratio for all different types of packing. When the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%, the percentage increase in heat transfer recorded: 15.8% for metal wire mesh, 16% for plastic cells, 16.1% for Kraft paper and 19.6% for cooling tower without packing. The figure indicates also that, the heat rejected from water has the highest value for case of metal mesh, followed by the case of plastic cell after which Kraft paper cell takes place. The cooling tower without packing has the lowest value of heat rejected.

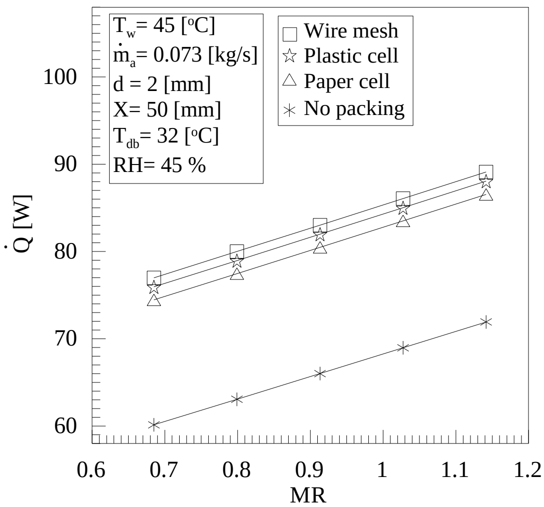


Fig. (16). Rejected heat versus water/air mass flow ratio (MR) with and without packing

Figure (17) indicates the vaporization rate versus water/air mass flow ratio (MR) with and without packing. The figure indicates that, the vaporization rate increases with the increase of water/air mass flow ratio for all different types of packing.

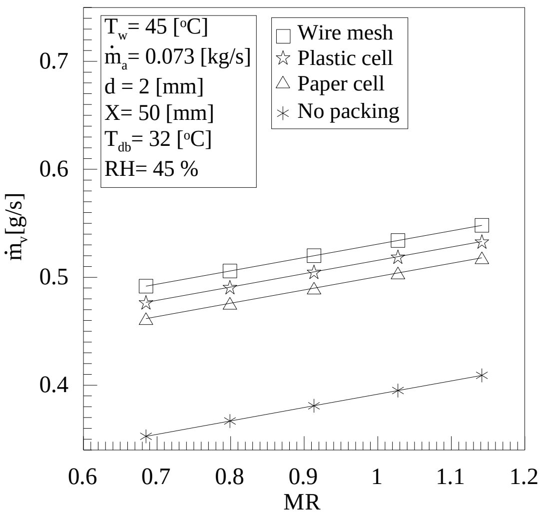


Fig. (17). Vaporization rate versus water/air mass flow ratio (MR) with and without packing.

From the data obtained it can be deduced that, when the water/air mass flow ratio is increased from 0.685 to 1.142 with a percentage increase of 66.7%, the percentage increase in the vaporization rate recorded: 12.2% for metal mesh, 12.6% for plastic cells, 13.1% for Kraft paper, and 17.1% for cooling tower without packing. The figure indicates also that, the vaporization rate from water has the highest value for case of metal mesh, followed by the case of plastic cell after which Kraft paper cell takes place. The cooling tower without packing has the lowest value of heat rejected.

The packing in cooling tower has great effect on pressure drop through it as it affects the power required for driving the fan. Figure (18) illustrates the pressure drop (ΔP) versus air mass flow rate at different types of packing.

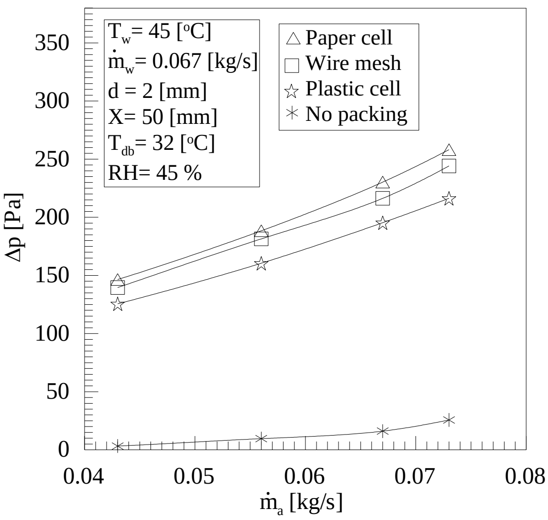


Fig. (18). Effect air mass flow rate on the pressure drop (ΔP) at different types of packing.

Generally, the pressure drop increases as shown in the figure with the increase of air mass flow rate for all different types of packing. When the air mass flow rate is increased from 0.043 to 0.073 [kg/s] with a percentage increase of 69.8%, the percentage increase in the pressure drop recorded: 76.2% for Kraft paper, 75% for metal mesh, 72.2% for plastic cells, and 702.5% for no packing.

Conclusions:

The experimental study for the effects of sprayer dimensions and packing on the performance of the cooling tower led to the following conclusions:

1- The cooling tower efficiency increases with the increase of water inlet temperature, air flow rate, interval distance between injection holes while it is decreased with the increase of injection holes diameter, water flow rate.
2- The heat rejected and mass transfer increases with the increase of each of hot water inlet temperature, air flow rate, water flow rate, water to air flow ratio and interval distance between injection holes, while it is decreased with the increase of injection holes diameter.
3- The packing of metal mesh has highest efficiency. The efficiency of cooling tower with metal packing is higher than that with plastic cells by 5.6%, with that of Kraft paper by 40.4% and with the case of no packing by 51.8 % respectively. However, the packing metal mesh is highest in pressure drop of other the types.

Nomenclature:

A: Cross section area of air outlet, (m^2).
C: Average air velocity, (m/s).
C_p Specific heat, kJ/kg. K
d : Diameter, *mm*
l : Length, mm
P : Pressure, P_a
R.H : Relative humidity
T : Temperature, °C
$\dot{m}$: Mass flow rate, Kg/s
$\dot{Q}$: Heat rejected rate, kW
X :Interval distance between injection, *mm*
MR : Water to air mass flow rate ratio

Greek symbols

Δ : Difference
η : Cooling tower efficiency
θ : Angle of manometer
ρ : Density, Kg/m^3
ω : Specific humidity, kg/kg_{da}

Subscripts

1: Inlet 2: Outlet
a: Air dp: Dry bulb
i: Inlet o: Outlet
v: vapor w : Water
wb: wet bulb

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