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THERMAL CHARACTERISTICS INVESTIGATION OF NATURAL DRAFT HYBRID (WET/DRY) COOLING TOWER

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Abstract: This study aims to analyse heat transfer mechanisms between water and air via direct contact (wet section) and indirect contact (dry section) in a natural draft hybrid cooling tower model. A prototype has been constructed based on geometrical, dynamic, and thermodynamic similarities to imitate a natural draft hybrid (wet/dry) cooling tower using natural draft hybrid technology. The experimental tests were carried out in summer (hot and dry) weather in accordance with Iraqi meteorological conditions, with splash fill packing measuring 15cm in height. This study aims to determine the influence of water flow rates and air flow rates on the cooling range, relative humidity, cooling capacity, and overall efficacy of a cooling tower. The experimental tests were carried out using four different water flow rates ranging from 7.5 to 12.0l/min and six different air velocities ranging from 0.4 to 2.4m/s while maintaining the intake water temperature constant 55ºC and the crosswind constant at zero (m/s). As a consequence of the experiments, it was discovered that the water mass flow rate and air velocity impacted all of the factors discussed earlier in varying degrees.

Key words: heat transfer, cooling tower, natural draft hybrid, water flowrate, air flow rate.

1. INTRODUCTION

Cooling towers discharge heat generated by cooling water in air conditioning systems or power plants to return the temperature to its starting value. The cooling medium in the tower can be either air or water, both of which can dissipate the heat generated by the condenser's hot water via direct or indirect contact. Cooling towers are classed as wet, dry, or mixed cooling towers based on their heat transmission method. Evaporative cooling is used in wet cooling towers. In these towers, the working fluid and the evaporated fluid are identical. Dry cooling towers employ a surface to separate the working fluid from the ambient air, then used to conduct heat transfer. As a result, they consume significantly less water for cooling. As a result, designers' key concern is the effect of various factors on cooling tower performance. Natural Draft Hybrid Cooling Towers (NDHCT) are extensively employed in various industrial operations, notably power plants. By spraying high-temperature water from nozzles onto packing fill, NDWCT disperses heat to the environment. This activity is carried out within the tower by three cooling zones; The rain zone, the spray zone, and the packing (fill) zone. The principal zone, which is the most efficient, is the packing or filling zone. The fundamental objective of the fill is to create a wide surface area, which increases the contact surface between water and air and slows the fall of water drops, allowing for more time. Summer in Iraq is scorchingly hot and dry. Kloppers and Kröger (Kloppers and Kröger, 2003, Kloppers and Kröger, 2005) concentrated on internal components and parameters to identify empirical correlations that account for fill loss coefficient data and demonstrated the effect of the Lewis factor, or Lewis relation, on the performance prediction of natural draft mechanical draft wet cooling towers. Kloppers and Kröger (Kloppers and Kröger, 2005, 3) examined the effect of temperature inversions throughout the night on the operation of natural draft wet cooling towers. Investigate the effects of the temperature inversion, the inversion profile's height, and the height at which air is dragged into the inversion. Qureshi and Zubair (Bilal and Zubair, 2006) found that the spray and rain zones absorbed a significant portion of the total heat rejected. The study of all zones cut the error in heat rejection estimates from 6.5% to 2.65%. Zhai and Fub (Zhai and Fub, 2006) found that wind-break walls placed on the lateral sides of cooling towers perpendicular to the cross wind are a simple and effective way to get back up to about 50 % of the cooling capacity lost when the wind blows.Gao et al. (Gao et al., 2008) found that temperature and cooling efficiency are influenced by the cross-wind. Temperature and cooling efficiency can decrease mostly by 6% and 5%, respectively. When the critical Froude number is less than 0.174. Also temperature

and cooling efficiency decrease with increasing cross-wind velocity, however, when it is greater than 0.174, they increase with increasing cross-wind velocity. Lemouari et al. (Lemouari, 2009) investigated the experimental analysis of simultaneous heat and mass transport phenomena between water and air in a packed cooling tower via direct contact. The primary goal is to investigate how air and water interact. Flow rates on the global heat and mass transfer coefficient and the rate of water evaporation into the airstream for various intake water temperatures. Ghassem et al. (Ghassem et al., 2009) built and validated a model of the three-tower zones (spray, packing, and rain). In the example study, excluding the spray and rain zones results in a 1.5 % error in calculating the tower volume. When the spray and rain zones are factored into the model, the error is reduced to 1.1% and 0.25%. The effect of the Lewis factor on wet-cooling tower performance prediction is investigated using the Bosnjakovic equation. Mahdi and Al-Hachami (Mahdi, 2015) are presented an experiments carried out in summer (hot and dry) and winter (cold and rainy) seasons, employing (100 mm) trickle fills according to Iraqi weather conditions. The water mass flow rate varied between 0.8 and 2.4 gpm, while the crosswind remained constant at zero (m/s). According to the results, the tower range, cooling capacity, and air temperature change are bigger in the winter than in the summer. Change in enthalpy and the ratio of m_w / m_a . They are bigger when it's hot outside than cold outside. This project will look at how well NDHCT works in Iraqi (hot and dry) conditions. Because Iraqis live in a hot and dry place, this paper aims to look at how well NDHCT works there.

2. EXPERIMENTS; METHODS AND PROCEDURES

Hamon-Sobelco LTD created the drilling platform using an Mt. Piper Power Station simulation - Delta Electricity tower. This tower has a height of 131 meters and a diameter of 98 meters. Several previous investigations used this tower as a reference point, including (Rafat, 2010; Wiliamson et al., 2008; alok and Rajput, 2012). The form of this tower is based on the similarity principle and is meant to resemble a cooling tower. The prototype's dimensions are a top outlet diameter of 58 cm, a bottom diameter of 98 cm, and a height is 131 cm. Reynolds and Froude numbers may be calculated from air velocity by comparing their dynamic and thermodynamic characteristics (Fr). Because Reynold's number is used, the air velocity in the model tower will be larger than in reality. Instead of the Froude coefficient, Froude numbers should be employed, where air velocity changes with the square root of model size. The prototype and model must reach Fr in velocity based on the experiment's thermal condition (Gao et al., 2008; Zhao, 2001).

$$\Delta Fr = \frac{inertia\ \ force}{gravity\ \ force}$$

$$\Delta Fr = \left(\frac{v_{out}}{\sqrt{\frac{\Delta\rho}{\rho_i} gl}} \right)_P = \left(\frac{v_{out}}{\sqrt{\frac{\Delta\rho}{\rho_i} gl}} \right)_M \quad (1)$$

v_{out} - wind velocity at outlet (m/s);
$\Delta\rho$ - difference in density (kg/m^3);
ρ_i - inlet density (kg/m^3);
g - gravitational constant (9.81 kg/m^2);
P - denotes for prototype;
M - denotes for model.

The hyperbolic tower is built in real dimensions according to the following equations (Gould and Kratzig, 1999) (figure 1).

$$4R^2/d_T^2 - Z^2/b^2 = 1 \quad (2)$$

$$b = d_T Z_H / \sqrt{(d_H^2 - d_T^2)} \quad (3)$$

$$b = d_T Z_U / \sqrt{(d_U^2 - d_T^2)} \quad (4)$$

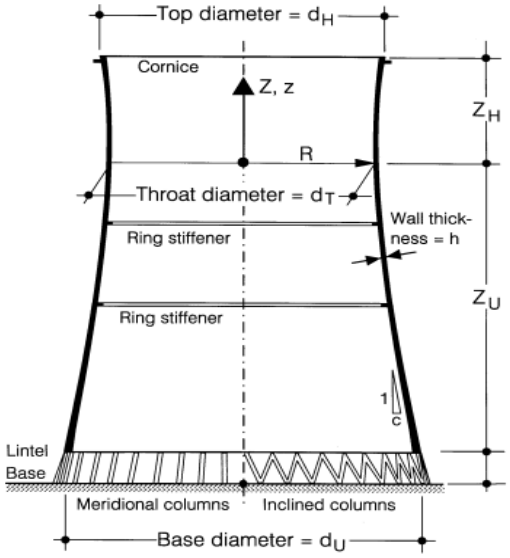

Fig. 1. Tower shell design

d_H - top diameter (61 cm);
d_T - throat diameter (53.5 cm);
d_U - diameter of the base (98 cm);
Z_U - height from the base to the throat (102.5 cm);
Z_H - height between the throat and the base (28.5cm);
R - radius at any height Z (cm).

The experimental setup used in this investigation is represented in figure 2.

1. Makeup water	9. Regulate valve.	17. Cold water tank.
2. Float valve	10. Hot water pump	18. Drain water tank.
3. Fill packing	11. Gate valve	19. Water thermocouple inlet dry section.
4. Water distribution nozzle.	12. Main water tank	20. supports
5. Heat exchanger	13. Electric element heater	21. Dry and wet bulb temperature inlet
6. U-tube monometer	14. Cold water pump.	22. Dry and wet bulb temperature outlet
7. Water flow meter	15. Water thermocouple outlet.	23. Air thermocouple inlet dry section.
8. Water thermocouple inlet	16. strainer. .	24. Air thermocouple outlet dry section

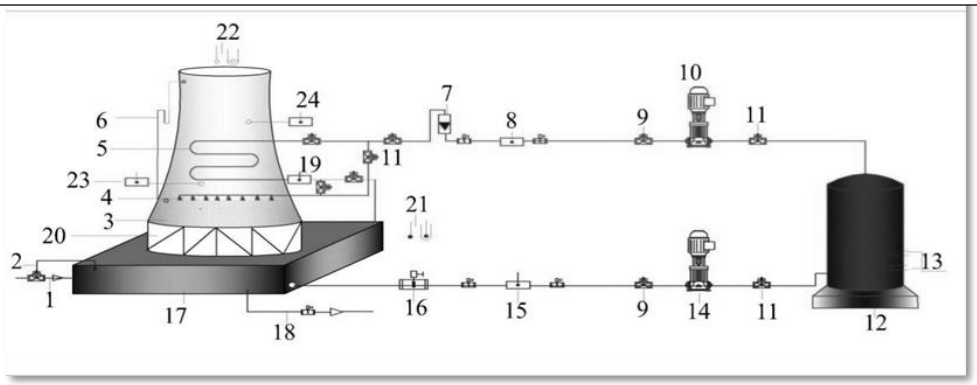

Fig. 2. The main parts of the natural draft hybrid cooling tower rig.

A packed cooling tower, a basin of cold water, an electric heater, a pump for pumping and dispensing the test solution, and a heat exchanger are employed in the testing procedure. Temperature and pressure sensors, as well as thermostats, are some of the other pieces of equipment that are used.

The following is the experimental procedure:

1. Initially, the heater was used to heat the water in the reservoir.
2. The pump was started when the water temperature in the reservoir reached the required level.
3. The gate valve was adjusted to achieve a 12 l/min water flow rate, and the flowmeter measurement was obtained.
4. Once the inlet and output water temperatures were steady, temperature recorder (thermocouple type K) data was obtained.
5. A humidity meter (model: GM-1363B) was used to measure the relative humidity of the air at the entrance and outflow at the same time.
6. A thermometer was also used to measure the temperature of the input air wet-bulb at the same time.
7. A digital anemometer measured air velocity at the fill inlet.
8. After that, while maintaining the input water temperature and flow rate constant, the air velocity was varied to determine the other parameters for the current state.
9. Repeat the procedure for water flow rates of 10.5 l/min, 9 l/min, and 7.5 l/min, respectively.

3. HEAT TRANSFER PHENOMENA

From an energy analysis standpoint, the parameters used to determine a cooling tower's performance are as follows:

The cooling range (CR): is the difference in temperature between the inlet and exit states of the water. The temperature differential may determine the range between the cooling tower's input and outlet:

$$CR=T_{cw.in}-T_{cw.out} \quad (5)$$

Tower approach: Tower approach is the difference between the outlet water temperature and the inlet air wet-bulb temperature.

$$\text{Tower approach} = T_{cw.out} - T_{awb.in} \quad (6)$$

Effectiveness: Thermal efficiency (effectiveness), defined as the ratio of actually released heat to maximum theoretical heat from the cooling tower, is the most important parameter of cooling tower performance.

$$\varepsilon=\frac{T_{cw.in}-T_{cw.out}}{T_{cw.in}-T_{awb.in}} \quad (7)$$

Cooling capacity (q): Cooling capacity is the amount of heat rejected or dissipated due to the mass flow rate of water, specific heat, and temperature difference.

$$q= \dot{m}_{cw} C_{p.cw} CR \quad (8)$$

Mass transfer coefficient: The mass transfer coefficient for enthalpy balance was determined for an elementary transfer surface by [15].

$$m_{air} dh_a = \alpha_m (h_i - h_{air}) \quad (9)$$

4. RESULTS AND DISCUSSION

Figure 3 shows the effect of the air velocity through the cooling tower on the cooling range when the water flow rate is changed and its temperature is kept constant. The figure shows that the cooling range increases with air velocity and water flow rate, where the increase is 31% at $\dot{m}_w$ =12 l/min, and V_a= 2.4 m/s due to the increase in the amount of heat dissipated from water as a result of the increase in heat transfer between air and water.

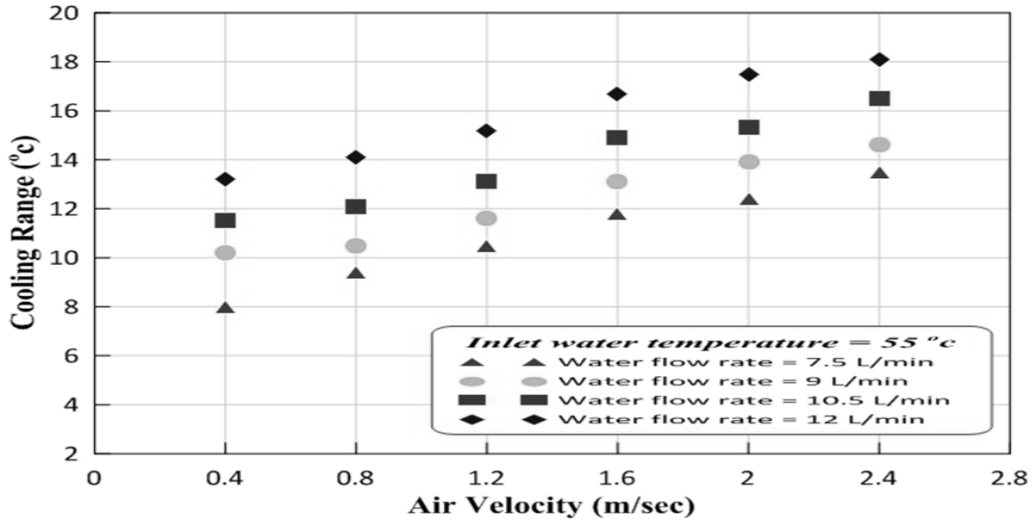

Fig. 3. Cooling range due to air velocity for various water mass flow rates at an inlet water temperature of 55 ℃

Figure 4 shows an increase in tower approach by 45% due to the increase in water flow rate through the cooling tower when the air velocity is about 2.4m/s. This increase is a large amount of heat transferred from the hot water. At the same time, the tower approach increase is about 17% at a water rate equal to 12 l/min. The percentage is small compared to before because there is not enough time to conduct heat exchange between water and air.

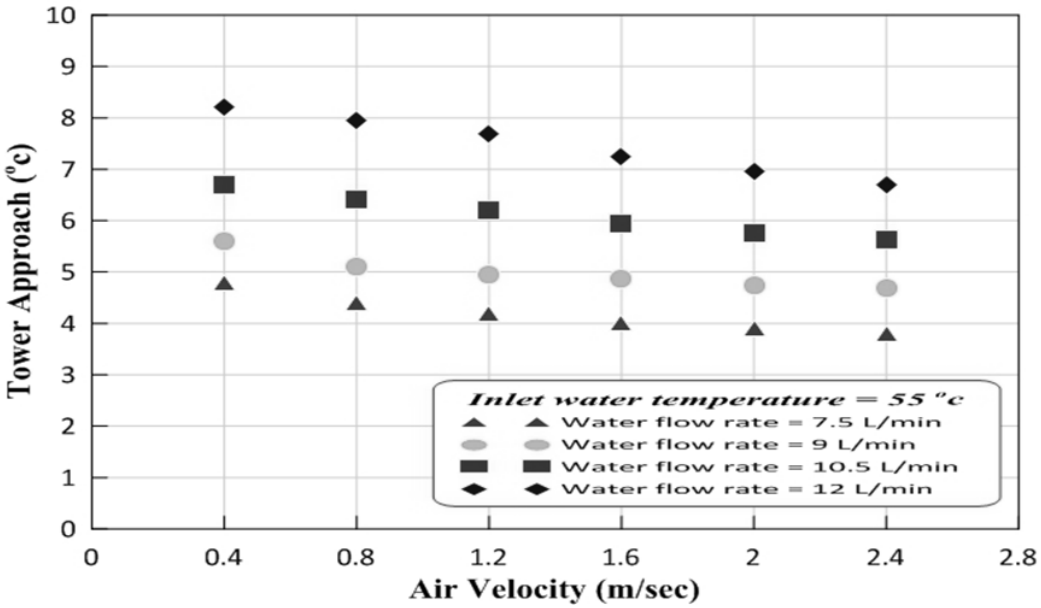

Fig. 4. Tower approach due to air velocity for various values of water mass flow rates at a 55 °C inlet water temperature.

Figure 5 shows that when the air velocity is constant (2.4m/s), increasing the amount of water flowing through the cooling tower lowers its effectiveness by approximately 13 %. At the same time, the rate of increase in effectiveness is low when the airspeed is increased with the stability of water flow (12 l/min). These results indicate a complex relationship between the amount of water and air velocity through the tower

and the need to determine the optimal ratio to obtain the best effectiveness.

Figure 6 shows that the cooling capacity through the tower increases by 30% in the case of an increase in

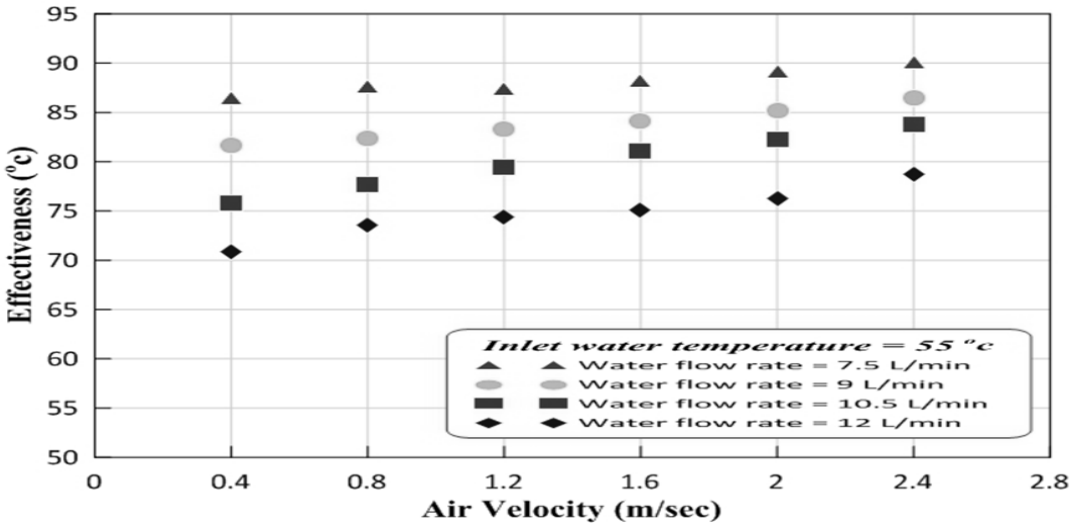

Fig. 5. Effectiveness due to air velocity for various values of water mass flow rates at 55 °C inlet water temperature.

air velocity from 0.4 m/s to 2.4 m/s and when increasing the water flow rate from 7.5 l/min to 12 l/min with constant water temperature.

Figure 7 shows the relationship of the ratio of water flow rate to airflow rate through the cooling tower with the velocity of air passing through the tower. It is clear from the figure that the increase in the air velocity by 500% leads to a decrease in the water-air ratio by 19%, which indicates an increase in the limits of the cooling range tower.

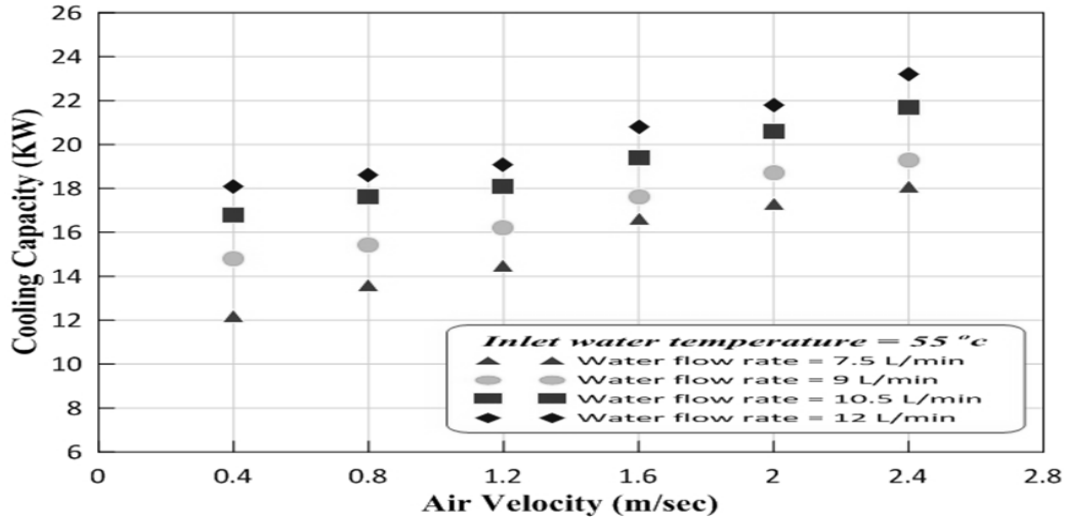

Fig. 6. Cooling capacity due to air velocity for various values of water mass flow rates at a temperature of 55 °C in the inlet water.

5. CONCLUSIONS

The hot water produced by the thermal procedures is cooled in the cooling tower through contact with the air. Therefore, the thermal performance of the cooling tower is of great importance. Many factors affect the performance of the cooling tower in the heat exchange between water and air. The results extracted from the present study showed that increasing the air velocity through the tower increases water evaporation, leading to a greater heat transfer. Results showed that the cooling rane, tower approach, and effectiveness of tower are increases by 31%, 17% and 13% respectively when ($\dot{m}_w$ =12 l/min, and Va= 2.4 m/s). Therefore, choosing an air velocity that corresponds to an ideal ratio of water and airflow through the tower is necessary to obtain the best performance and reduce losses.

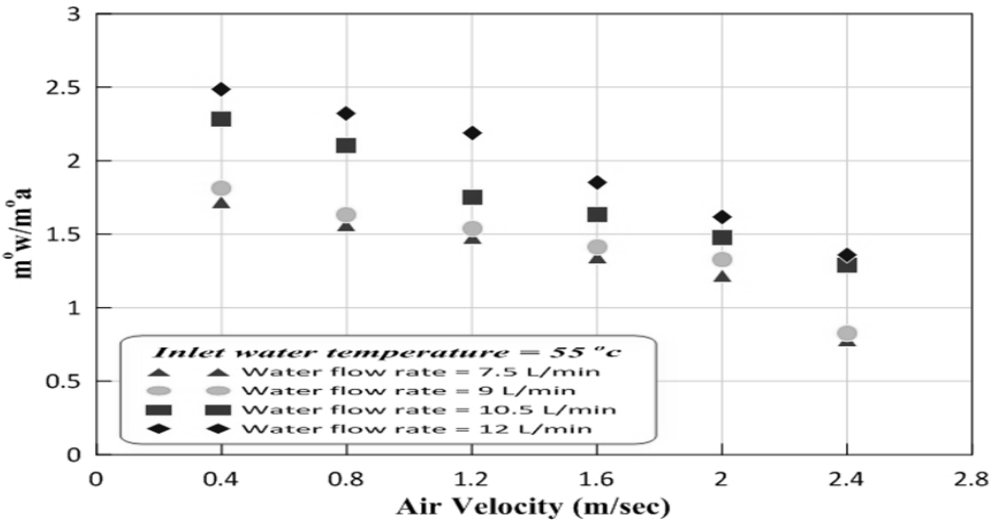

Fig. 7. Change in $\dot{m}_w$ / $\dot{m}_a$ due to air velocity for various water mass flow rates at an inlet water temperature of 55 ℃

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