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*Research article*

## Experimental study of a natural draft hybrid (wet/dry) cooling tower with a splash fill type

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**Abstract:** Cooling towers have such a significant influence on work and efficiency that researchers and designers are working tirelessly to enhance their performance. A prototype design for a natural draft hybrid (wet/dry) cooling tower has been created, relying on geometrical, dynamic, and thermodynamic similarities. Based on Iraqi weather, experiments have been conducted using splash fill (150 mm) in summer (hot and dry) weather conditions. This study investigated heat transfer mechanisms of both air and water in a natural draft hybrid cooling tower model (NDHCTs), both directly (wet section) and indirectly (dry section). The tower is filled with splash-style packing, and the warm water is spread throughout the building using sprayer nozzles. The influences of water flow rates, fill thickness, and air velocity on the cooling range, approach, cooling capacity, thermal efficiency of the cooling tower, water evaporation loss into the air stream and water loss percentage were explored in this study. The experimental were carried out with four different water flow rates, ranging from 7.5 to 12 (Lpm) litres per minute, and eight different air velocities, all while keeping a constant inlet water temperature and a zero (m/s) crosswind. Data has been gathered, and performance variables have been determined. The findings demonstrate that the cooling tower's efficacy increases when the water flow rate is low, and the cooling range increases with increasing air velocity and decreases with increasing water flow rate; for a 7.5 Lpm water flow rate and a 2.4 m/s air velocity, it expanded to 19.5 °C. The cooling capacity increased to 23.2 kW for a water flow rate of 12 Lpm and an air velocity of 2.4 m/s.

**Keywords:** cooling range; wet bulb temperature; cooling tower; performance factors; air velocity; splash fill type; heat exchanger

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**Abbreviations:**  $T_{wi}$ : Inlet water temperature;  $T_{wo}$ : Outlet water temperature; CR: Cooling range;  $T_{wb}$ : The temperature of the ambient wet bulb;  $\dot{m}_a$ : Air mass flow rate;  $\dot{m}_w$ : Water mass flow rate;  $q$ : Cooling capacity;  $\omega$ : Humidity ratio;  $\varepsilon$ : Cooling tower effectiveness;  $i_{air}$ : Enthalpy of air;  $Q_w$ : Water flow rate

## 1. Introduction

Cooling towers are used in many industrial processes, like power plants, nuclear power plants, refrigeration and air conditioning systems. They are used to remove heat from the air or the water. Wet, dry and hybrid cooling towers are three types, based on how they move heat around. There are wet cooling towers where evaporative cooling is used (Rokni 2016) [1] (He 2015) [2]. They have the same working fluid as the liquid that evaporates, so they don't need to be separated. Dry cooling towers work by capturing the working fluid from the outside air and using heat transfer to move the heat away from the liquid. Because dry cooling towers don't use evaporation to cool, they use a lot less water than wet cooling towers. As for a hybrid (wet/dry) cooling tower, this method can save about 20% of the water used by a traditional wet-type cooling tower. Replacement of wet cooling towers with dry ones might be a good idea if there is insufficient water. Designers need to consider how different factors affect the performance of cooling towers (Al-Waked & Behnia, 2004) [3], (He et al., 2015) [4]. Regarding how well cooling towers work, the most important things to watch are relative humidity and weather conditions outside. So many projects have been done in this setting. Many places don't have a lot of water, and it is used as a heat transfer medium in natural draft hybrid (wet/dry) cooling towers (NDHCTs). People use a lot of different ways to keep things cool.

Direct air-cooled systems offer significant water savings [numerous variables, including the wind speed and direction in the surrounding area]. Three types of hybrid cooling tower fills are available: splash fill, film (honey cell) fill and trickle fill (Xia et al., 2017) [5].

Splash fills are intended to spread water into many droplets. At the droplet surfaces, both heat and mass transfer occur. Water drains down the fillings, colliding with several levels of splash bars. Collisions transfer moisture and heat through the formation of new droplets. Contact with the fills extends the duration that waterfalls down the tower are retained. The authors established a correlation between the tower characteristics and the water/air mass flow ratio, stating that the water/air mass flow ratio is one of the elements affecting the values of the tower characteristics (Bedekar et al., 1998) [6].

Following splash fills, film fills were visible. Corrugated wet cooling tower fills and corrugated cooling pads were launched simultaneously. Polystyrene, high-polyvinyl chloride or density polythene, ceramic brick, polypropylene, asbestos-cement paper coated with neoprene, expanded stainless steel sheet, and cardboard are all instances of film fillers. We evaluated the following material types: Z-shaped strip, sine wave, embossed flat sheet, honeycomb or rough hexagonal, laminated plastic plate fills, single corrugated facer and structured cellular fills. Contrary to the fill splash, the flowing water in the film fill occurs as a thin water film. In recent years, trickle fills have been added. They are typically constructed from metal or plastic grids in numerous patterns, and water flows along the filling grid instead of splashing. Trickle fills cause tiny water droplets and water films that cling to the surface.

This study aims to undertake an experimental analysis utilizing a formerly made and adapted direct connection of the cooling tower “evaporative liquid” to limit the influence of water and air

ratio, according to the features of the cooling tower (Li, YingYuan et al., 2020) [7].

Many researchers have studied cooling towers, with some focusing on experiments with various packages. The current work focuses on inside tower parameters such as nozzles, fills and water mass flow rate, along with the effect of wind (as an environmental factor), including experimental analyses. (Kloppers & Kröger, 2005) [8] showed that the empirical equation for better-correlated fills had a novel shape that lost more constant statistics than previously discovered other versions of the empirical equation. Because it accounts for the spectrum shear and drag forces, a general equation is used to accurately correlate measured pressure loss coefficients for packing fills (trickle, splash and film) under practical operational conditions. (Zhai & Fu, 2006) [9] study ways to increase cooling towers' effectiveness on windy days. According to the results, the vertically placed wind-breaks on the sides of the cooling towers lateral to the crosswind represented an efficient and simple way. This could restore almost half of the reduced ratio of the cooling capacity. This study investigates the connection between cooling competence recovery and wind-break wall size, identifying an optimal scale of wind-break walls. The simultaneous mass transfer and heat phenomenon between air and water by frontal connection in a crowded cooling tower has been examined experimentally (Lemouari et al., 2009)[10]. The efficacy of the water-to-air flow ratio was studied based on the universal mass transfer and heat coefficient and the ratio of evaporative water into the air stream at various access water temperatures, which is a critical part of the research. (Saleh Mahdi & Al-Hachami, 2015) [11] investigated the natural draft cooling towers that can be used in cold, wet, and hot, dry environments. Summer has higher relative humidity, air enthalpy and efficiency than winter, which can be recorded as an advantage in summer, indicating high latent heat transfer. The tower's main features are range and cooling capacity, which are greater in the winter. In winter, the heat added to the rejected air is greater, which affects the green zone phenomenon. As the winter water-to-air flow rate value decreases, the total winter water consumption increases. Using a counter-flow natural draft hybrid (wet/dry) cooling tower, examined heat transfer performance under windless and crosswind conditions and used the wind-creator device to emulate the current natural characteristics wind speed profile. This study focused on the effects of inlet water temperature, crosswind velocity, and water mass flow ratio on the varying temperature of the water and the effectiveness of the natural draft hybrid (wet/dry) cooling tower. (Wang et al., 2010) [12] used guiding channels with inlet airflow to monitor and test the thermal performance of a natural-draft wet cooling tower model in crosswinds. Under various crosswind velocities, three patterns of air guiding channels with different setting angles (60, 70, and 80) were tested. The results showed that the airflow rate and cooling efficiency increase dramatically when directed to inlet air. (Grobelaar et al., 2013) [13] showed that when cooling towers are full of splash fills or trickles with almost anisotropic or isotropic flow resistance, the airflow out of the fill is wrong or crosses the flow of the water; this is especially true at the cooling tower inlet when the fill hangs down into the air inlet region or when the fill loss coefficient is low. Lastly, the result shows that the number of transfer characteristics or fill Merkel for cross-counter flow is in the middle of fills for pure counter-flow and pure cross-flow. Experimentally. (Gao et al., 2013) [14] The studied temperature change and efficiency are increased by infrequent winds and may reduce by 6% and 5%, respectively. The temperature differential and efficiency decrease as the crosswind speed increases when the crucial Froude number is less than 0.174, and the comparable wind speed is 0.45 m/s. When it reaches 0.174, however, the temperature difference increases with increasing crosswind speed. In (Dewanjee et al., 2020) [15], experiments were carried out to investigate the performance and characteristics of a cooling tower with a new

shape (splash and film) and fillings that were regularly used. The study's effectiveness must be improved. Cooling towers allow a higher volume of air to travel through them, dissipating more heat. It was determined that the approach of cold water to the wet-bulb air temperature has been one of the parameters that impact the heat transfer range of cooling. According to our experience, the newly designed packaging performs better than the standard type. Studies on cooling towers on various sides of the cooling towers have been conducted to improve the process. (Gao et al., 2009) [16] Under the same ambient meteorological parameters and windless conditions, both circulating water temperature difference and coefficient of efficiency increase with the increasing circulating water inlet temperature and decrease with rising water flow rate. The cross-wind has a great influence on the circulating water temperature difference and coefficient of efficiency. It can decrease them by about 6% and 5%, respectively. (Ghoddousi et al., 2021) [17] Cooling towers are the entrance to the visible, given the requirement to observe water and reduce water use in cooling towers. The present cycle examined the function of cooling towers in the current cycle and the growth of wealth. constellations. In the performance trade-off, the principal designs of wet cooling and leasing towers consume the most water, while dry cooling towers consume the least. Simply put, hybrid cooling towers offer both benefits but are more expensive. The present work investigates the thermal performance of a hybrid cooling tower operating in Iraqi climate conditions of the Splash fill type. The climate in Iraq during the summer is hot and dry. Also, this type of tower has not previously been tested in Iraqi climate conditions.

## 2. Experimental work

The natural draft hybrid (wet/dry) cooling tower rig used in this work was built in Baghdad with the resources of Middle Technical University/Technical Engineering College-Baghdad using a criterion of similarity to an actual tower constructed already in Australia. The test rig can be used as either a natural draft hybrid (wet/dry) cooling tower or a fan-assisted damp cooling tower. Its components include the tower shell, the base tower, the nozzles system, a cold water basin and a water reservoir with an electric heater, pumps and flow-meter, A distributor, A heat exchanger and main fan components of this test's equipment. The research experiment includes similarity criteria such as geometric similarity, kinematic similarity, dynamic similarity and thermal similarity. The model test tower (NDHCT) used for testing was built at a scale ratio of 1:100 compared to the original cooling tower. The original cooling tower stands 131.1 m tall and has a bottom diameter of 98.0 m and a top diameter of 58.18 m. According to similarity theory and simulation, the geometrical proportion of the prototype cooling tower is 1:100. The cooling tower's measurements are 58 cm × 98 cm × 131 cm (top outlet diameter, bottom diameter and height). Reynolds number (Re) and Froude number (Fr) are derived from dynamic and thermodynamic similarities. Similarity should be measured using the Froude number, where air velocity is inversely proportional to model size. Experimentally determined thermal condition of the prototype and model revealed that the velocity must exceed Froude number (Fr) [19]. According to the kinematic similarity, the model tower's air velocity ratio must be equal to that of the original tower: that is,

$$\left(\frac{v_a}{v_s}\right)_P = \left(\frac{v_a}{v_s}\right)_M \quad (1)$$

where  $v_a$  is the air velocity at the tower's top and  $v_s$  is the crosswind velocity at the height of the

tower's outlet, both in meters per second. The P and M subscripts represent the prototype and model towers, respectively. The driving force of buoyancy and the inertial force of the transverse wind are the two most crucial components; thus, the test must guarantee that they are taken into account. The number of Froude because the usual and original towers are the same, the Froude number similarity must be fulfilled instead of the Reynolds number (Gao et al., 2008) [19].

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

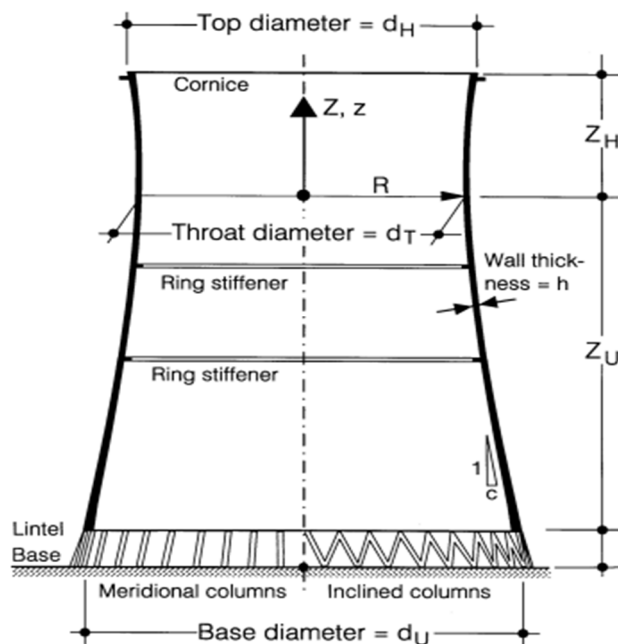
$$\Delta Fr = \left( \frac{v_a}{\sqrt{\frac{\Delta \rho_a * g * L}{\rho_i}}} \right)_P = \left( \frac{v_a}{\sqrt{\frac{\Delta \rho_a * g * L}{\rho_i}}} \right)_M \quad (2)$$

The  $\rho_i$  represents the density of the air in the cooling tower ( $\text{kg/m}^3$ ), and  $\Delta \rho = \rho_a - \rho_i$ , while  $\rho_a$  represents the density of the air outside the cooling tower. The  $\Delta \rho$  represents the difference in density ( $\text{kg/m}^3$ ).  $L$  (m) is the effective height of the cooling tower, and  $g$  is the gravitational acceleration ( $9.81 \text{ kg/ms}^2$ ). The real-size hyperbolic tower was constructed using the following equations of the generating curve, as represented in Figure 1:

$$4R^2/d_T^2 - Z^2/b^2 = 1 \quad (3)$$

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

$$b = d_T Z_U / \sqrt{(d_U^2 - d_T^2)} \quad (5)$$

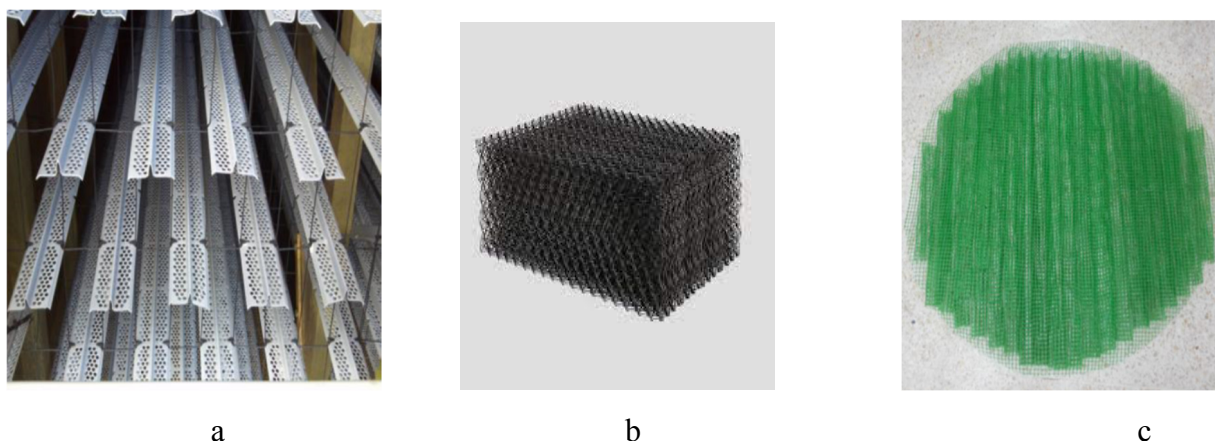


**Figure 1.** Tower shell design (Wai-fah, et al 1999) [20].

With,

- $d_U$  base diameter (98 cm),
- $d_T$  throat diameter (53.5 cm),
- $d_H$  top diameter (58.17 cm),
- $z_H$  height from throat to top (102.5 cm),
- $z_U$  height from base to throat (28.5 cm),
- R radius at any height Z (cm),

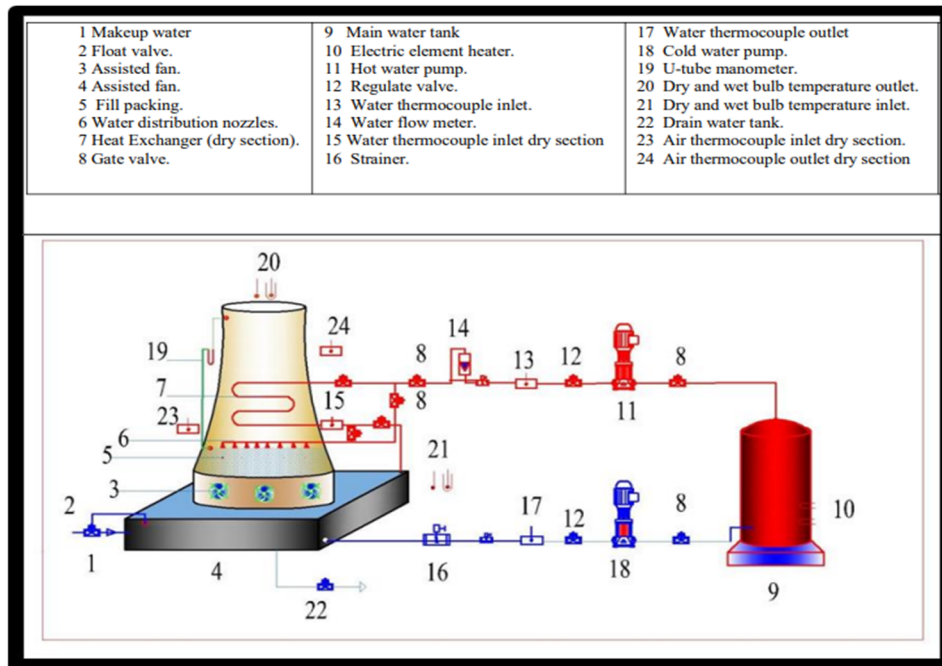
Packing in cooling towers is done with splash fill, the most common method. A thickness of 15 cm is utilized to conduct the test. A diameter of 98 cm fills the base of the shell tower under the spray zone, as seen in Figure 2. Hot water is used to simulate load; it is temperature-controlled at 55 °C using two 3000-watt heaters (both Italian\_made) to reach the required temperature. They are connected to the main water tank; an individual thermostat and power supply are used to regulate the temperature of each heater in the system. The water flow rate changes to 7.5, 9, 10.5 and 12 Lpm. In this study, which looked at splash fills with 15 cm, nozzles with a diameter of 2 mm were used. Some of the things that were measured were the dry bulb temperatures and relative humidities of the air at the tower's entrance and exit, the water temperatures at the intake and outlet, the air velocity at the outlet, the water mass flow rate, and the pressure drop along the tower shell.



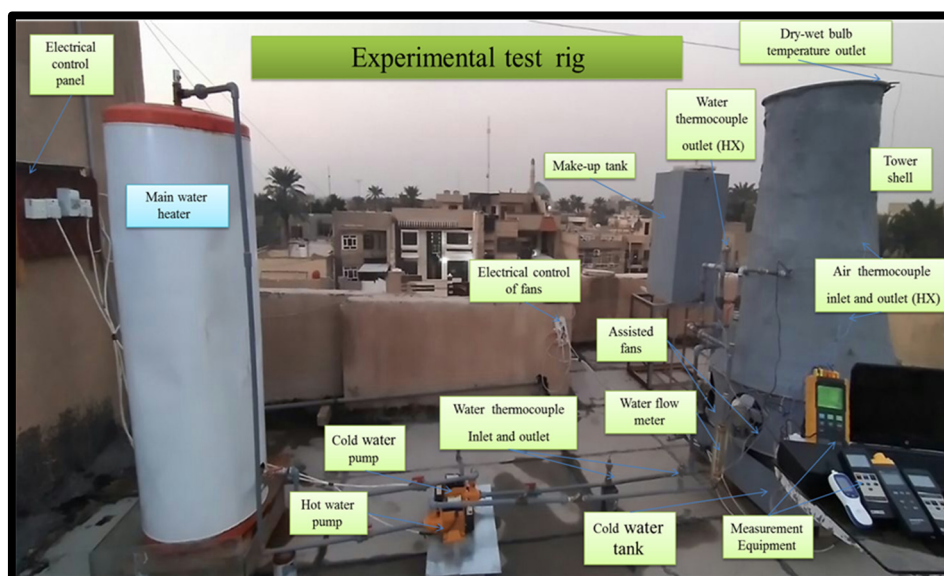
**Figure 2.** Splash fill, different designs.

Pipe connections, pumps, valves, reservoirs and nozzles are examples of water system components. The piping system comprises 1.27 cm (0.5 inches) pipes. The system ensures that the main tank is linked to the nozzles (hot water), and the main tank is linked to the basin tank (cold water). The main tank is also connected to the makeup tank. Two electrical pumps ( $Q_{\max} = 35$  liter/min and  $H_{\max} = 40$  m) complete the cycle. The hot water pump starts from the main tank to the nozzles, whereas the cold water returns from the tower basin main tank. With a capacity of 200 litres, the main tank serves as the primary reservoir. The reservoir basin is made of galvanized metal and measures  $100 \times 100 \times 30 \text{ cm}^3$ . This reservoir can be accessed from the upper side, where the tower is. Two water ball valves, one connected before the water pump on the supply pipe and the other on the return pipe, control the flow rate of the water. The process of spraying water that covers the top surface part of the fill spots is linked to a net of 1.27 cm (0.5 inches) pipes and is accomplished by utilizing the seven nozzles of equal 2 mm diameters. During experimental tests, many parameters,

such as water mass flow rate, dry and wet air temperatures at both entrance and exit, air humidities at both entry and exit, the water temperatures at inlet and outlet, air mass flow rate, air velocity at the outlet, pressure drop and wind velocity, must be measured. The following devices are required to perform these measurements: anemometer, thermometer, humidity meter and manometer. Figure 3 is a schematic diagram of the test rig components, measuring equipment and locations. Figure 4 is a test rig photograph. Table 1 lists the details of the measuring instruments used in the experimental studies.



**Figure 3.** Experimental apparatus schematic diagram.



**Figure 4.** Photograph of experimental apparatus (front view).

**Table 1.** Specifications of measuring instruments.

NO.	Instrument	Supplier	Type	Range	Accuracy
1	Digital thermometer	(Lutron:BTM-4208SD)	Air and water temperature (°C)	(-50-1370)	±0.1 °C
2	Humidity meter	(BENETECH:GM-1363B)	Relative humidity (%)	(0-100)	±5%
3	Flow meter	(ZYIA Instrument Company)	Water flow rate (L/min)	(3-70)	±2%
4	Anemometer	Lutron:BTM-4208SD	Air velocity (m/sec)	(-0.2-20)	±5%
5	Manometer	Eisco	Pressure drop (mm H <sub>2</sub> O)	(0-30)	±2%

### 3. Heat transfer phenomena in the cooling tower

According to the graphical depiction, air velocity significantly affects a cooling tower's performance. Increased air velocity brings more air into contact with the hot water, which absorbs heat quicker. The cooling range is the temperature differential between the water temperatures at the input and output.

$$\text{Cooling Range} = (T_{\text{water}})_{\text{in}} - (T_{\text{water}})_{\text{out}} \quad (6)$$

The tower approach is the difference between the outlet water temperature and the inlet air wet-bulb temperature.

$$\text{Tower approach} = (T_{\text{water}})_{\text{out}} - (T_{\text{wet, air}})_{\text{in}} \quad (7)$$

Effectiveness is one of the cooling tower performance parameters. It can also be referred to as thermal efficiency, defined as the ratio of actually released heat to maximum theoretical heat from the cooling tower.

$$\text{Effectiveness}(\epsilon) = \frac{(\text{Range})}{(\text{Range} + \text{Approach})} = \frac{(T_{wi} - T_{wo})}{(T_{wo} - T_{wb})} \quad (8)$$

Water heat rejection is calculated by multiplying the mass flow ratio of water (kg/sec) by the specific temperature and heat difference. The rate of heat lost by water and air is given by the following:

$$q = \dot{m}_w * C_{p,w} * [(T_{\text{water}})_{\text{in}} - (T_{\text{water}})_{\text{out}}] = \dot{m}_a * C_{p,a} * [(i_{\text{air}})_{\text{out}} - (i_{\text{air}})_{\text{in}}], \quad (9)$$

Evaporation loss is the amount of water lost due to cooling duty. In theory, for every 1,000,000 kCal of heat rejected, the evaporation quantity equals 1.8 m<sup>3</sup>. The following (Perry) formula can be used.

$$\text{Evaporation loss (m}^3\text{/hr)} = 0.00085 \times 1.8 \times Q \text{ (m}^3\text{/hr)} \times (\text{CR}) \quad (10)$$

(CR) denotes the temperature difference between the inlet and outlet water (cooling range). (Q) denotes the volumetric flow rate of water.

Evaporation loss can be calculated using the following equation.

$$\text{Evaporation loss (kg/hr)} = m_a (\omega_2 - \omega_1) \quad (11)$$

The amount of water lost due to evaporative cooling can be calculated as follows:



$$\text{Percent loss} = \frac{\text{Evaporation loss (kg/hr)}}{\text{inlet flow water (kg/hr)}} * 100\% \tag{12}$$

#### 4. Results and discussion

To check the reliability of using the experimental apparatus heat and mass transfer balance, Eq (9) is used. The results are shown in Figure (5), where the heat balance Data within  $\pm 10\%$  were used. The heat balance of the apparatus could be claimed to be satisfactory.

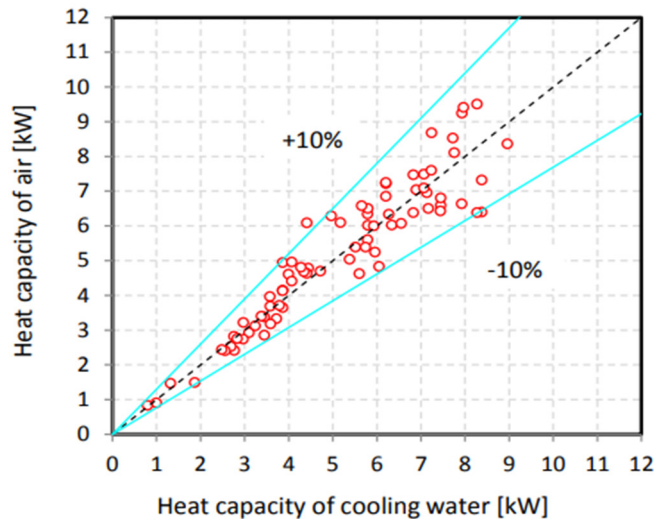


Figure 5. Heat balance of the experimental apparatus.

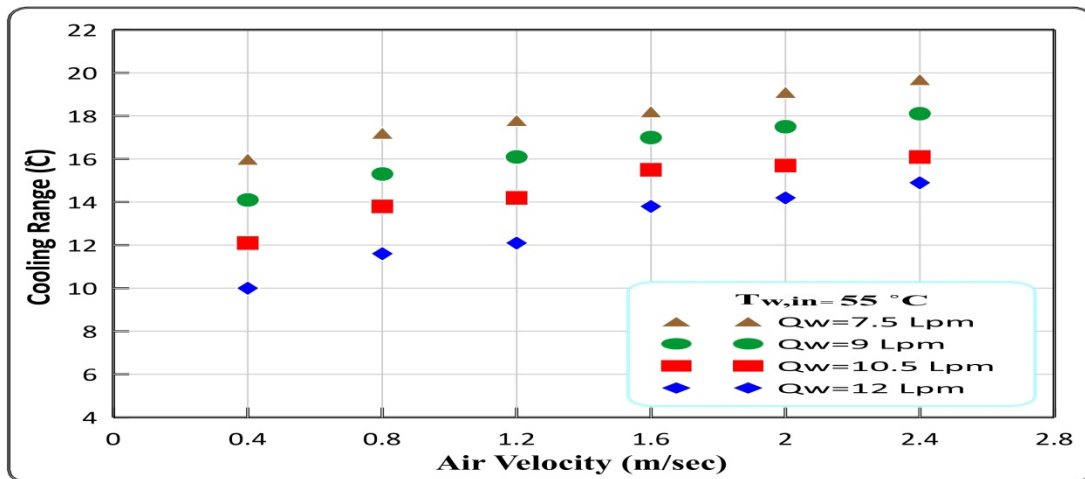
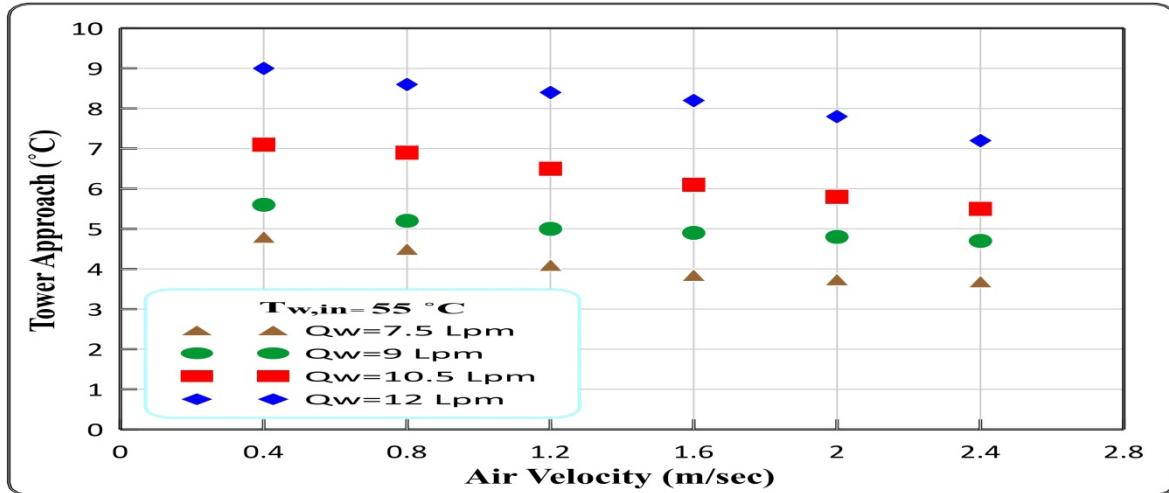


Figure 6. The cooling range due to air velocity for various water flow rates at an inlet water temperature of 55 °C.

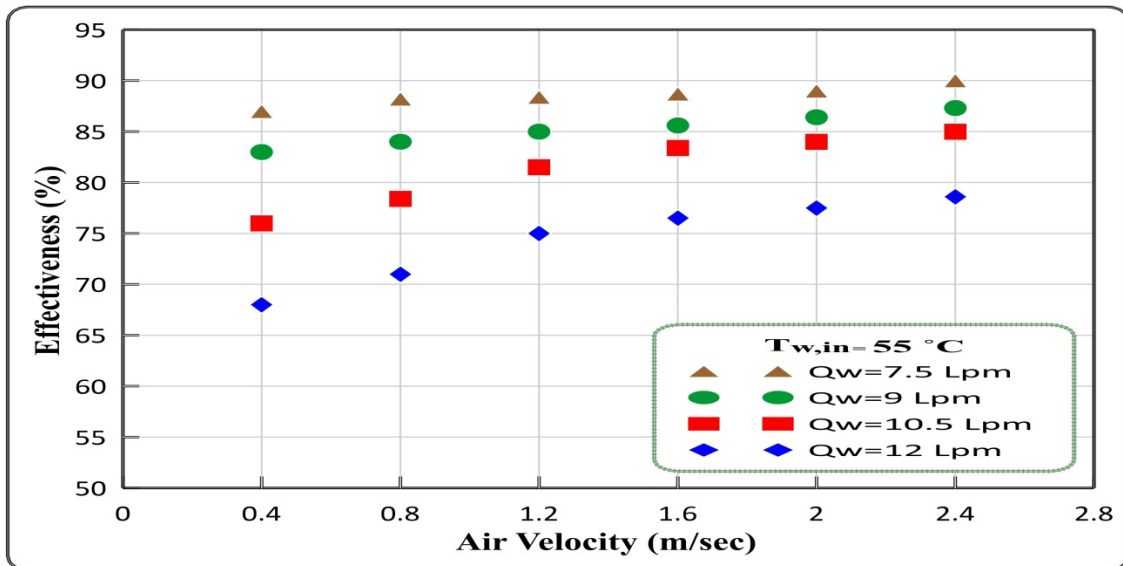
As shown in Figure 6, the cooling tower's range increases with increasing air velocity and decreases with increasing water flow rate; for a 7.5 Lpm water flow rate and 2.4 m/s air velocity, it expanded to 19.56 °C. When the water flow rate was 12 Lpm and the air velocity was 0.4 m/s, the

temperature dropped to 10.22 °C.

Figure 7 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 2.4 m/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 Lpm. The percentage is small compared to before because there is not enough time to conduct heat exchange between water and air.



**Figure 7.** Tower approach due to air velocity for various water mass flow rates at an inlet water temperature of 55 °C.

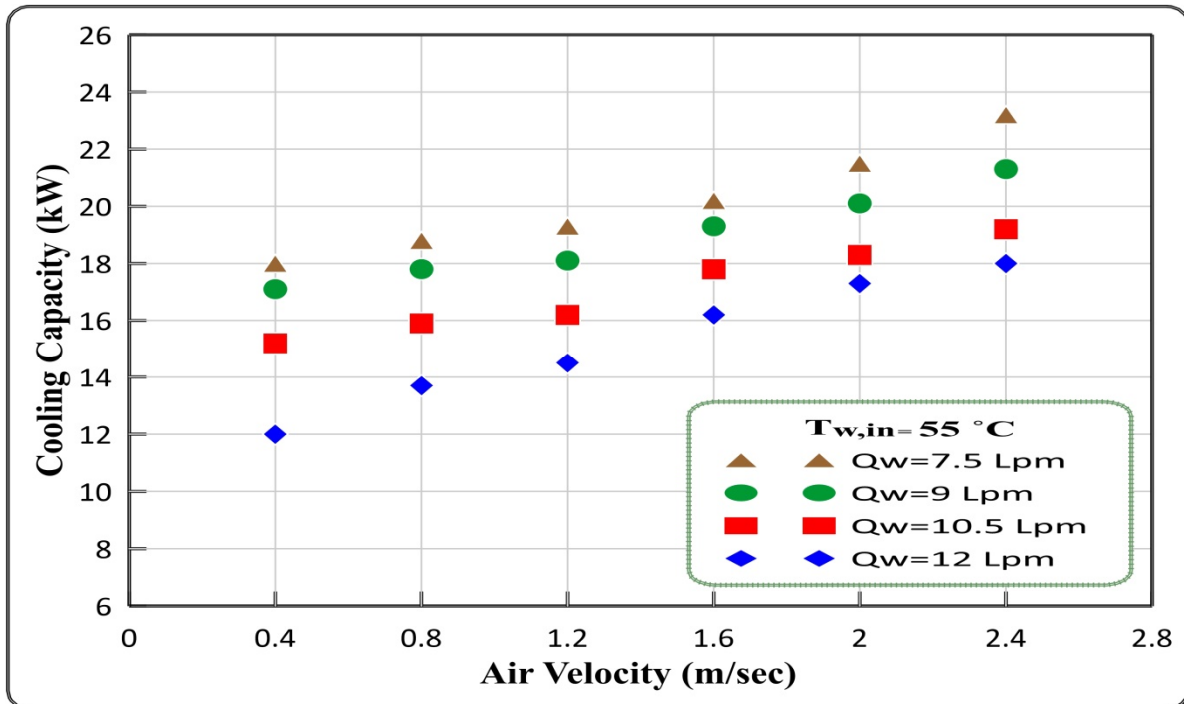


**Figure 8.** Effectiveness due to air velocity for various water mass flow rates at an inlet water temperature of 55 °C.

Figure 8 shows that when the air velocity is constant (2.4 m/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 a stable water flow (12

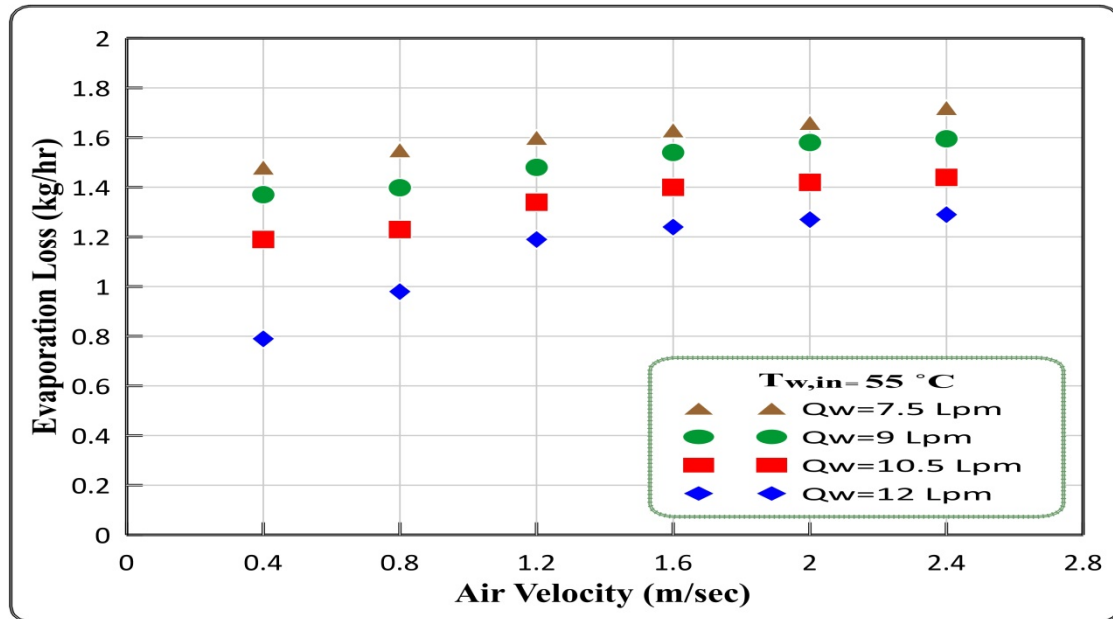
Lpm). These results indicate a complex relationship between the amount of water and air velocity through the tower and the need to determine the optimal ratio to obtain the best effectiveness.

Figure 9 shows that the cooling capacity through the tower increases by 30% in the case of an increase in air velocity from 0.4 m/s to 2.4 m/s and when increasing the water flow rate from 7.5 Lpm to 12 Lpm with constant water temperature. The cooling capacity gradually increased as the air velocity increased. Cooling capacity increased to 23.24 kW for a water flow rate of 12 Lpm and an air velocity of 2.4 m/s. As shown in Figure 8, it decreased to 12.15 kW for a 7.5 Lpm water flow rate and a 0.4 m/s air velocity.



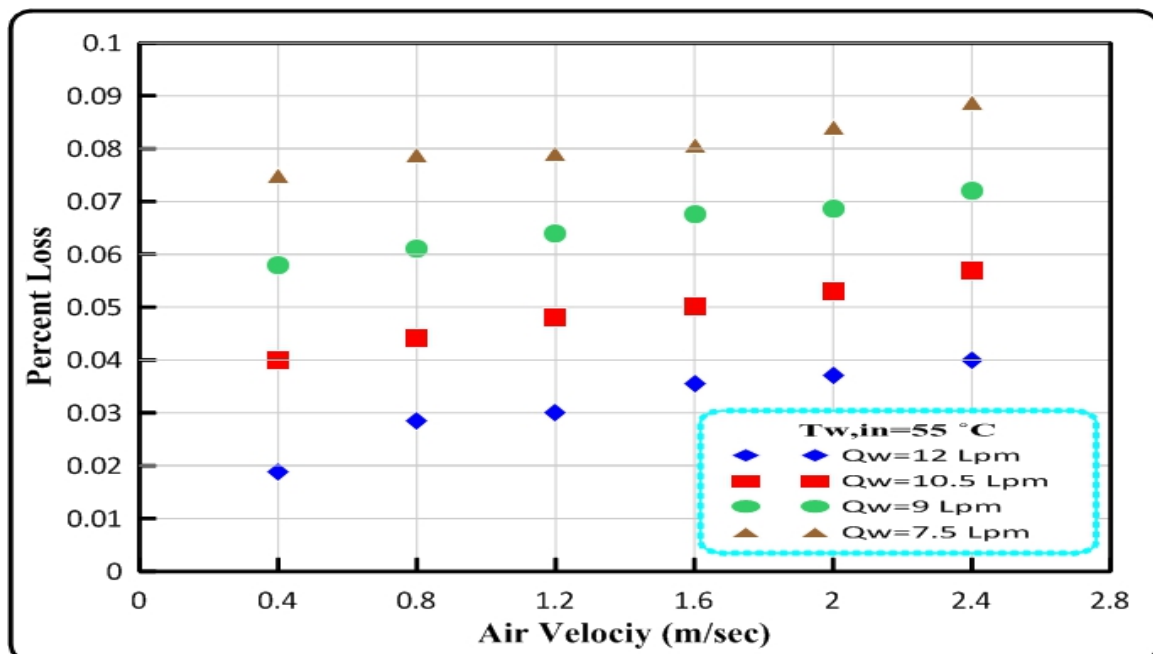
**Figure 9.** Cooling capacity due to air velocity at an inlet water temperature of 55 °C for different water mass flow rates.

As shown in Figure 10, evaporation loss decreased to 0.84 kg/h for a water mass flow rate of 12 Lpm and an air velocity of 0.4 m/s. As a result of increased evaporation loss, more makeup water is required to increase evaporation loss. As a result, we must select an intermediate airspeed with high cooling efficiency and low evaporation loss. We must also consider the water flow rate because evaporation losses increase at low flow rates when the ratio of water flow changes rather than the air velocity. The loss ratio changes dramatically.



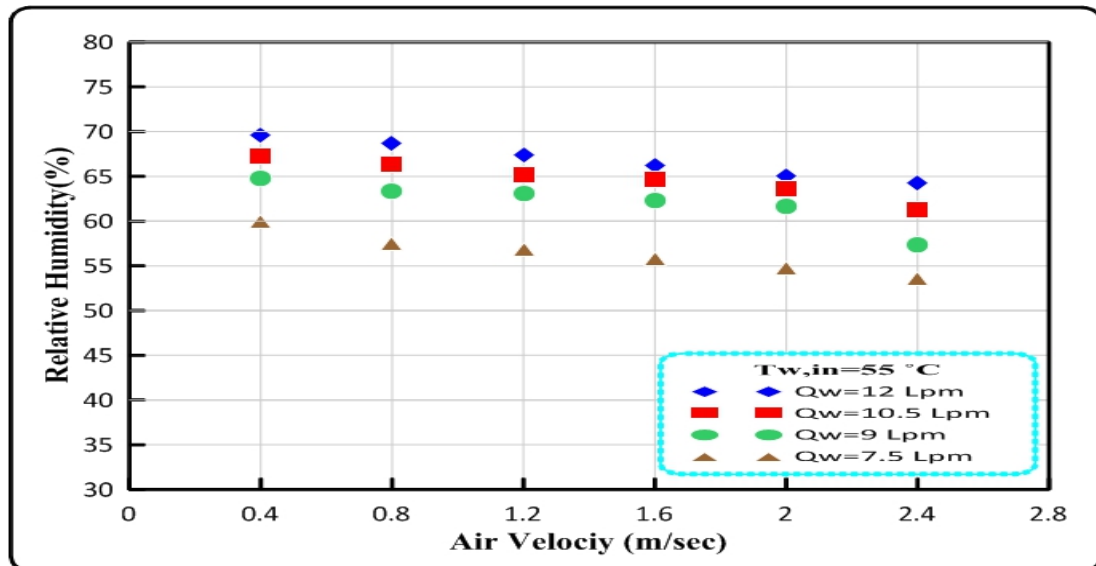
**Figure 10.** Evaporation loss due to air velocity for various water mass flow rates at an inlet water temperature of 55 °C.

As shown in Figure 11, percent loss increased to 0.089 for a water flow rate of 7.5 Lpm and an air velocity of 2.4 m/s, and it decreased to 0.075 at an air velocity of 0.4 m/s at the same water flow rate. At the same time, percent loss was 0.031 for a water flow rate of 12 Lpm and an air velocity of 2.4 m/s, while it decreased to 0.019 at an air velocity of 0.4 m/s at the same water flow rate.

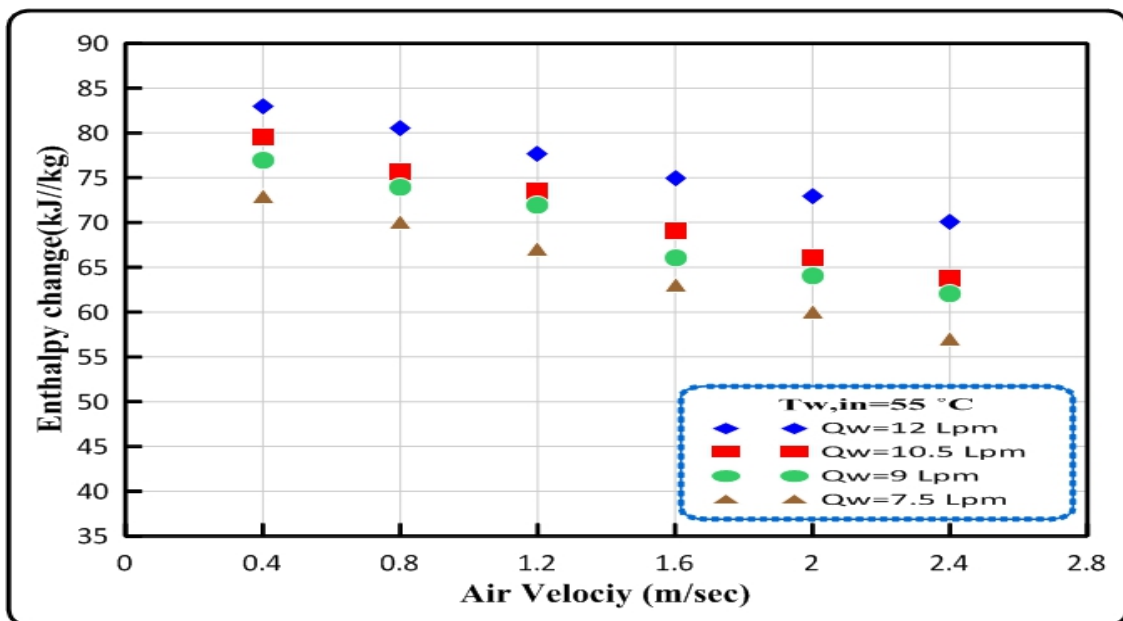


**Figure 11.** Water loss due to air velocity for different water mass flow rates at an input water temperature of 55 °C.

The relationships between relative humidity and air velocity are shown in Figure 12. The change in relative humidity is rapid at a high air velocity of 2.4 m/s and a low water flow rate of 7.5 Lpm, but it is lower than that when the air velocity is the same, but the water flow rate is 12 Lpm. The primary reason for this behavior is that, as the air velocity rises, the air distribution based on the falling water is not equal, owing to the influence of turbulence within the tower. The air to water ratio is higher in one area and lower in another, resulting in an overall decrease in air humidity at the outlet.



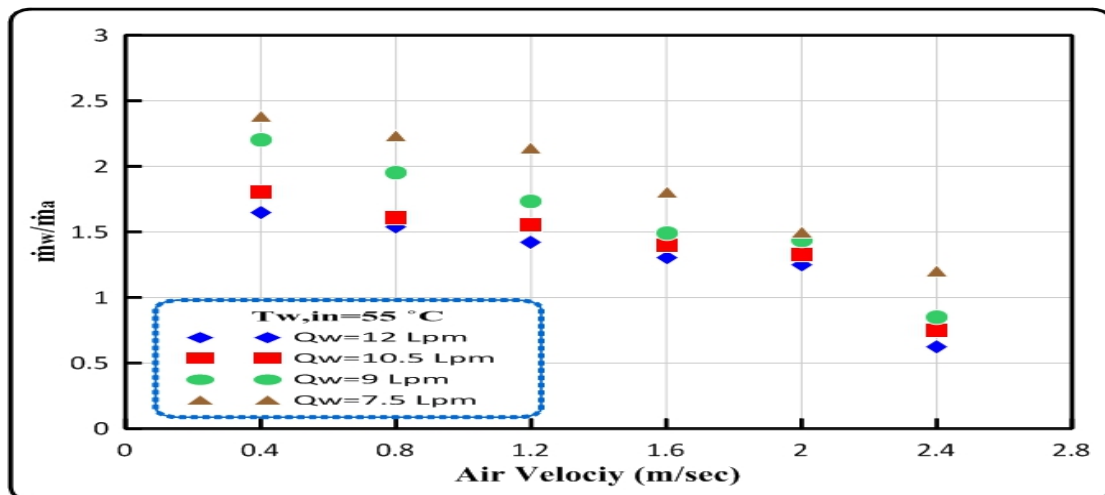
**Figure 12.** Relative humidity changes due to air velocity for various water mass flow rates at an inlet temperature of 55 °C.



**Figure 13.** Change in enthalpy due to air velocity for various water flow rates at an inlet temperature of 55 °C.

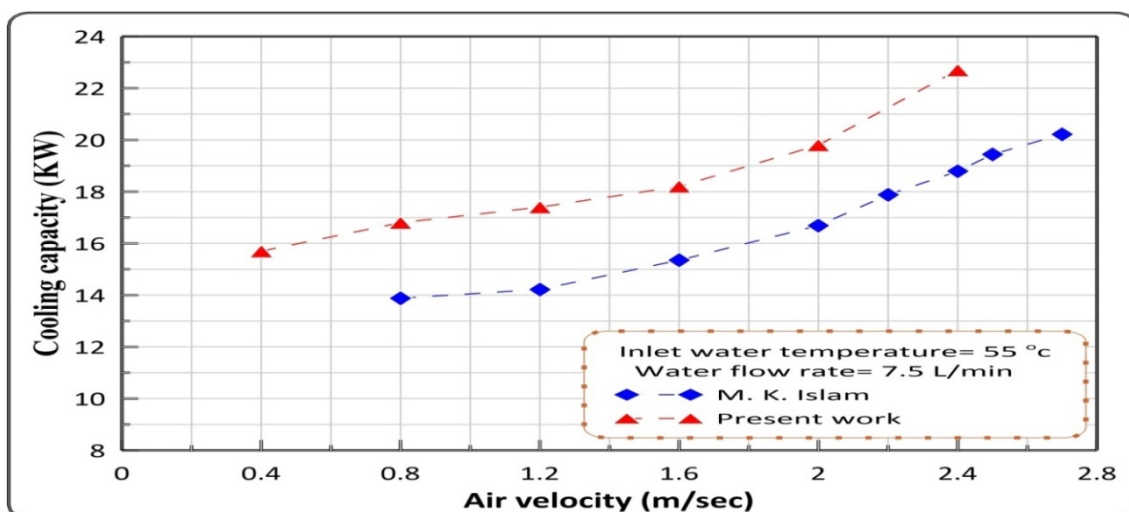
Figure 13 depicts the air enthalpy's behavior as a function of air velocity. Air enthalpy behaves similarly to relative humidity, with enthalpy dropping rapidly at 58 kJ/kg for low flow rates of 7.5 Lpm at a higher air velocity (2.4 m/sec) and less quickly for higher water flow rates of 12 Lpm. At a faster (0.4 m/sec) air velocity. The enthalpy of air is a function of temperature that will be influenced by air temperature and vapor content.

Figure 14 shows the water-to-air mass flow ratio  $\dot{m}_w/\dot{m}_a$  Which is the most important factor in how well a cooling tower works. Lower ratios are better. Where there was less ratio, it went down to 0.5 for 7.5 Lpm of water flow and 2.4 m/s of air velocity. At the same time, it went up to 2.54 for 12 Lpm of water flow and 0.4 m/s of air velocity.



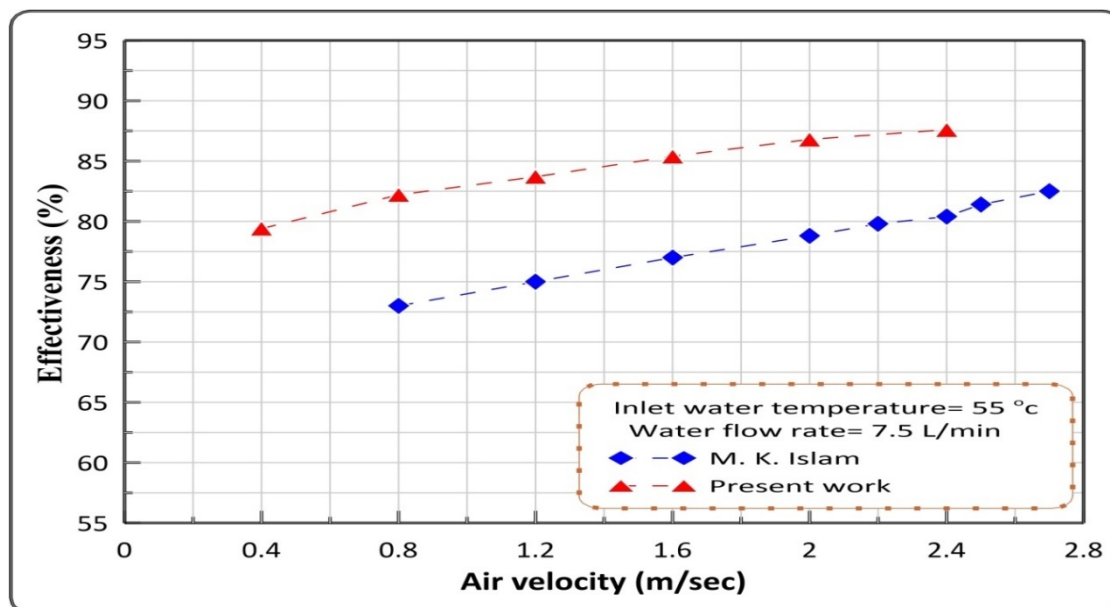
**Figure 14.** Change in " $\dot{m}_w/\dot{m}_a$ " due to the velocity of the air for various water mass flow rates at an inlet water temperature of 55 °C.

## 5. Comparison



**Figure 15.** Comparison of the concluded effect of air velocity on cooling capacity with work (Mahmud et al., 2014) [21].

Figures 15 and 16 compare the experimental results shown by (Mahmud et al., 2014) [21], for cooling capacity and effectiveness with a change in the air for the cooling tower and the effect of inlet water temperature and fill area. As air velocity increases, cooling capacity and effectiveness increase linearly. The two studies' different cooling capacity and effectiveness values are due to the different operating conditions and fill areas of the two experimental apparatuses.



**Figure 16.** Comparison of the concluded effect of air velocity on the effectiveness with work (Mahmud et al., 2014) [21].

## 6. Conclusions

As a result, cooling tower efficiency should be a top priority. A cooling tower's efficiency (effectiveness) is determined by factors such as inlet water temperature, air velocity, fill area, fill spacing and water flow rate.

The primary goal of this experiment was to improve efficiency by installing a better water distribution system, rearranging splash type fill and determining the effect of air velocity on cooling tower performance. The tests were carried out in a hybrid cooling tower with cross-flowing air. As air velocity increased, cooling tower performance improved, but so did evaporation and drift loss, necessitating the use of additional makeup water. As a result, it is critical to select an ideal air velocity that will result in greater effectiveness and less loss.

## Conflict of interest

All authors declare no conflicts of interest in this paper.

## References

1. Rokni M (2016) Performance comparison on repowering of a steam power plant with gas turbines and solid oxide fuel cells. *Energies* 9: 399. <https://doi.org/10.3390/en9060399>
2. He SY (2015) Performance improvement of natural draft dry cooling towers using wetted-medium evaporative pre-cooling. *The University of Queensland*, 144. <https://doi.org/10.14264/uql.2015.514>
3. Al-Waked R, Behnia M (2004) The performance of natural draft dry cooling towers under crosswind: CFD study. *Int J Energy Res* 28: 147–161. <https://doi.org/10.1002/er.958>
4. He S, Guan Z, Gurgenci H, et al. (2015) Experimental study of the application of two trickle media for inlet air pre-cooling of natural draft dry cooling towers. *Energy Convers Manag* 89: 644–654. <https://doi.org/10.1016/j.enconman.2014.10.031>
5. Xia L, Li J, Ma W, et al. (2017) Water consumption comparison between a natural draft wet cooling tower and a natural draft hybrid cooling tower—An annual simulation for luoyang conditions. *Heat Transf Eng* 38: 1034–1043. <https://doi.org/10.1080/01457632.2016.1216975>
6. Bedekar SV, Nithiarasu P, Seetharamu KN (1998) Experimental investigation of the performance of a counter-flow, packed-bed mechanical cooling tower. *Energy* 23: 943–947. [https://doi.org/10.1016/S0360-5442\(98\)00044-9](https://doi.org/10.1016/S0360-5442(98)00044-9)
7. Yuan W, Sun FZ, Liu RQ, et al. (2020) The effect of air parameters on the evaporation loss in a natural draft counter-flow wet cooling tower. *Energies* 13: 6174. <https://doi.org/10.3390/en13236174>
8. Kloppers JC, Kröger DG (2005) Refinement of the transfer characteristic correlation of wet-cooling tower fill. *Heat Transfer Eng* 26: 35–41. <https://doi.org/10.1080/01457630590916266>
9. Zhai Z, Fu S (2006) Improving cooling efficiency of dry-cooling towers under cross-wind conditions by using wind-break methods. *Appl Therm Eng* 26: 1008–1017. <https://doi.org/10.1016/j.applthermaleng.2005.10.016>
10. Lemouari M, Boumaza M, Kaabi A (2009) Experimental analysis of heat and mass transfer phenomena in a direct contact evaporative cooling tower. *Energy Convers Manag* 50: 1610–1617. <https://doi.org/10.1016/j.enconman.2009.02.002>
11. Saleh Mahdi Q, Al-Hachami MR (2015) Performance comparison for NDWCT using trickle fill at different weather conditions. *Int J Eng Trends Technol* 19: 134–139. <https://doi.org/10.14445/22315381/IJETT-V19P223>
12. Shahali P, Rahmati M, Alavi SR, et al. (2016) Experimental study on improving operating conditions of wet cooling towers using various rib numbers of packing. *Int J Refrig* 65: 80–91. <https://doi.org/10.1016/j.ijrefrig.2015.12.004>
13. Wang K, Zhong SF, Zhao YB, et al. (2010) Experimental research of the guiding channels effect on the thermal performance of wet cooling towers subjected to crosswinds—Air guiding effect on cooling tower. *Appl Therm Eng* 30: 533–538. <https://doi.org/10.1016/j.applthermaleng.2009.10.015>
14. Grobbelaar PJ, Reuter HCR, Bertrand TP (2013) Performance characteristics of a trickle fill in cross- and counter-flow configuration in a wet-cooling tower. *Appl Therm Eng* 50: 475–484. <https://doi.org/10.1016/j.applthermaleng.2012.06.026>



15. Gao M, Shi YT, Wang NN, et al. (2013) Artificial neural network model research on effects of cross-wind to performance parameters of wet cooling tower based on level Froude number. *Appl Therm Eng* 51: 1226–1234. <https://doi.org/10.1016/j.applthermaleng.2012.06.053>
16. Dewanjee S, Kabir SMH, Das UD (2020) Performance enhancement of induced draft counter flow wet cooling tower with different types of modified shaped fill assembly. *J Eng Res Reports*, 41–53. <https://doi.org/10.9734/jerr/2020/v16i217165>
17. Gao M, Sun FZ, Zhou SJ, et al. (2009) Performance prediction of wet cooling tower using artificial neural network under cross-wind conditions. *Int J Therm Sci* 48: 583–589. <https://doi.org/10.1016/j.ijthermalsci.2008.03.012>
18. Ghoddousi S, Anderson A, Rezaie B (2021) Analysis of windbreaker combinations on steam power plant natural draft dry cooling towers. *Eur J Sustain Dev Res* 5: em0161. <https://doi.org/10.21601/ejosdr/10952>
19. Li X, Gurgenci H, Guan ZQ, et al. (2019) A review of the crosswind effect on the natural draft cooling towers. *Appl Therm Eng* 150: 250–270. <https://doi.org/10.1016/j.applthermaleng.2018.12.147>
20. Gao M, Zhong SF, Wang K, et al. (2008) Experimental research of heat transfer performance on natural draft counter flow wet cooling tower under cross-wind conditions. *Int J Therm Sci* 47: 935–941. <https://doi.org/10.1016/j.ijthermalsci.2007.07.010>
21. Gould PL, Kratzig WB (1999) Cooling tower structures. *Structural Engineering Handbook*, Boca Raton: CRC Press LLC.
22. Mahmud T, Islam MK, Salam B (2014) Experimental study of forced draft cross flow wet cooling tower using splash type fill. 2013: 2–7. Available from: <https://www.researchgate.net/publication/270579420>.



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