

Analyzing heat transfer variations with hole quantities in multi-layered flat-plate cooling towers

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Abstract

Cooling towers are essential industrial heat exchangers that cool water by exposing it to air, promoting evaporation and subsequent temperature reduction. Despite extensive research on performance enhancement, the optimal design configuration remains uncertain. This study examines the impact of hole quantity and shape on the thermal performance of a multi-layered flat-plate cooling tower. Circular holes in three configurations, 80, 120, and 185 holes, were tested at inlet temperatures of 65°C and 75°C. The cooling tower has a total height of 2.4 meters, with each plate measuring 0.7 × 0.5 meters and arranged at a 15° angle. Experimental results show that the highest heat transfer rate occurs at 75°C with 185 holes, while the largest heat transfer coefficient is achieved at 65°C with the same configuration. These findings emphasize the significant role of hole quantity and geometry in optimizing cooling tower performance. The results offer valuable insights for industrial applications, particularly in improving cooling efficiency in power plants and manufacturing processes.

Keywords:

Cooling tower, hole quantity, circular holes, heat transfer rate, heat transfer coefficient

1 Introduction

In the industrial sector, thermal equipment is widely used for plant operations and generates excess heat, which can lead to thermal fatigue. To address this, an effective cooling system dissipates heat from machinery [1]. These systems function as heat absorbers, preventing overheating. Cooling processes typically use air or water, with water preferred for large-scale applications like cooling towers [2].

Cooling towers, among the most common cooling systems, act as heat exchangers with water and air as working fluids. They lower high-water temperatures for reuse [3]. As shown in Fig. 1, key components include a fan, transmission device, water conservancy impeller, tower body, fill zones, and water basin [4].

Cooling towers offer several advantages, including lower construction costs, the use of easily accessible cooling fluids, and the ability to recycle these fluids for repeated use. This efficiency makes them widely used in various industrial applications such as chemical plants, power generation, and manufacturing processes [5].

Previous studies have investigated various parameters affecting cooling tower performance. Rajai [6] studied cooling towers with a zig-zag pattern and found that optimal heat transfer occurred with round hole counts between 45 and 55. Mustika [7] analyzed different hole shapes and concluded that square holes provided the best heat transfer rate. Suansyah [8] examined cooling towers with different hole counts and reported that the highest heat transfer rate was achieved at 250 holes with an inlet temperature of 80°C.

Additionally, Aulia [9] focused on triangular holes and found that the optimal number was 65 at an inlet temperature of 85°C. However, despite these insights, the optimal hole count and heat transfer characteristics of multi-layered cooling towers with round holes remain unclear.

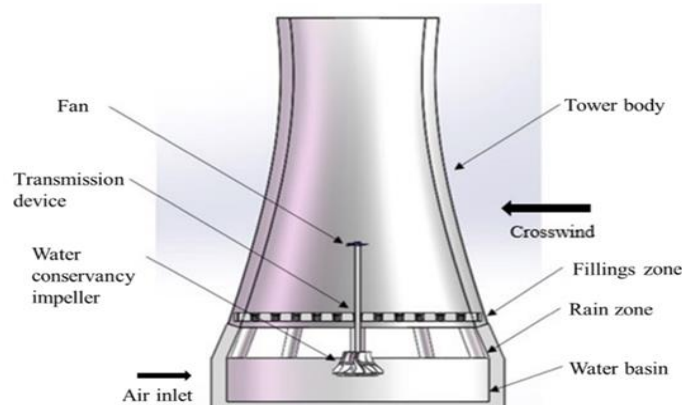


Fig. 1. Cooling tower

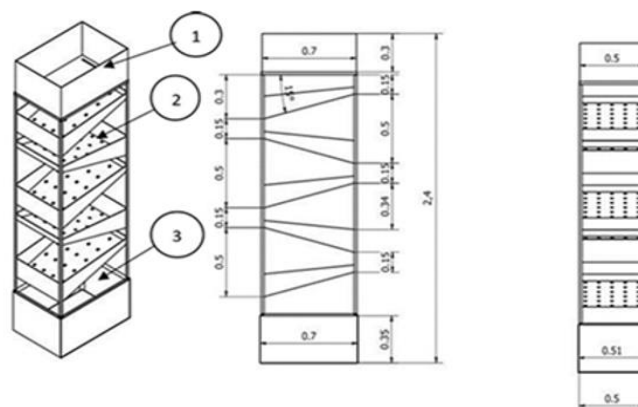
Building on these findings, this study examines how hole count variations (80, 120, and 185) affect multi-layered cooling tower performance. By bridging gaps in previous research and analyzing inlet temperatures (65°C and 75°C), this study aims to optimize cooling tower efficiency for industrial applications.

2 Research methods

This study employs an experimental approach conducted in the Thermal Engineering Laboratory, Mechanical Engineering Study Program, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Syiah Kuala University. The experimental variables include the number of round holes, 80, 120, and 185, on flat plates, along with inlet temperature variations of 65°C and 75°C.

The multi-layered cooling tower designed for this study comprises an upper reservoir, five layered flat plates, and a lower reservoir. Heated water is pumped into the upper reservoir at an initial temperature T_1 , then flows over the flat plates, where it cools by natural convection until reaching temperature T_2 before falling into the lower reservoir. This system design aims to enhance heat transfer, thereby improving machine efficiency.

The dimensions of the multi-layered cooling tower (Fig. 2) include an overall height of 2.4 m, with both the upper and lower reservoirs approximately 0.3 m in height and 0.7 m in length, and each plate is set at a slope of around 15°.



Description:

1. Upper reservoir
2. Flat plate
3. Bottom sump

Fig. 2. Cooling tower design

The design of the flat plate for the cooling tower incorporates dimensions of 0.7 m × 0.5 m, with an aluminum plate thickness of 0.3 mm. The design of the flat plate can be seen in Fig. 3.

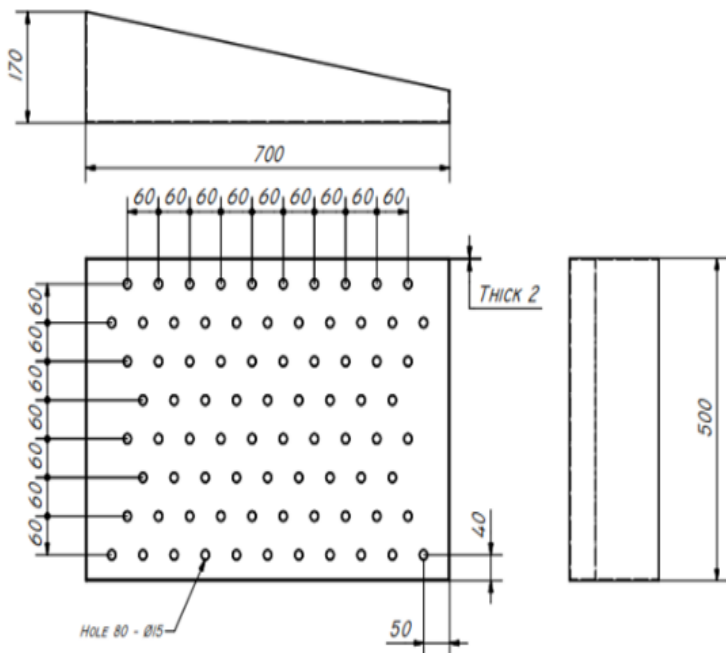


Fig. 3. The design of the flat plate

In this study, the measured parameters include the temperature of the water as it falls from the upper reservoir to the flat plate, the temperature as the water flows across the flat plate, and the temperature as it drops from one plate to the next (Fig. 4). Temperature measurements are taken every minute over 15 minutes, with the results used to calculate the average values.

3 Results and discussion

The parameters measured in this study encompass the temperature of the incoming heated water, the temperature as water descends from each plate, the temperature as it flows across each plate, and the temperature of the exiting water from the cooling tower. The data collection methodology is depicted in Fig. 5.

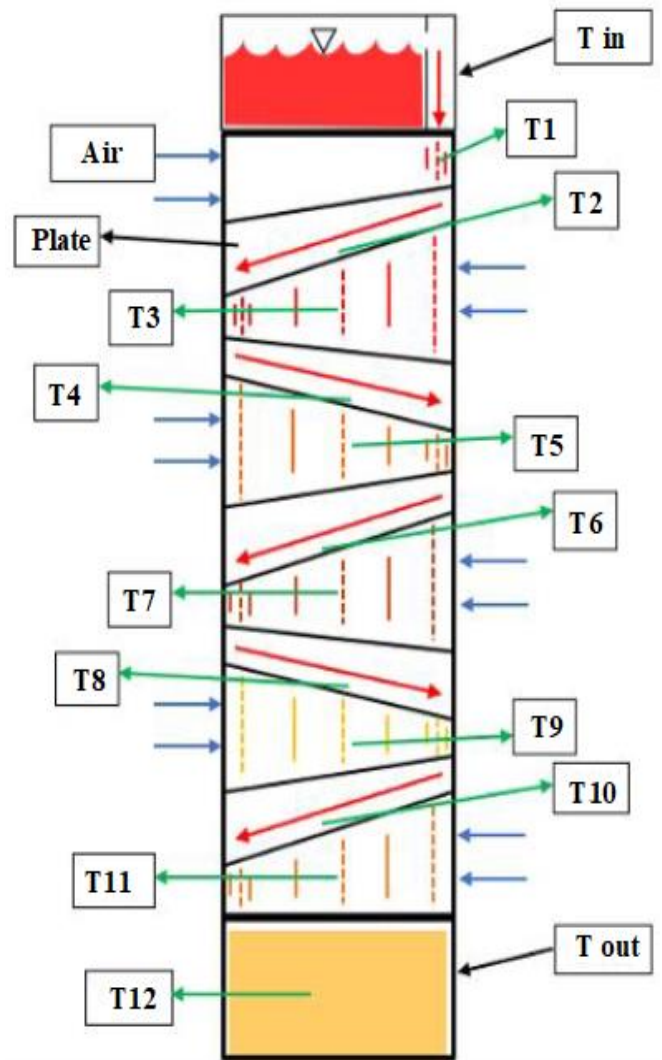


Fig. 4. Data collection points in the cooling tower

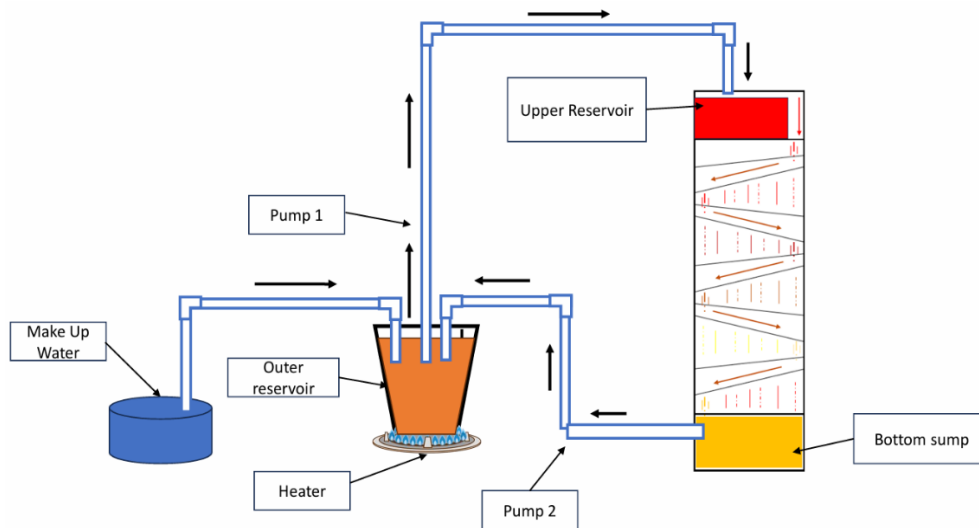


Fig. 5. Schematic of data capture

3.1 Temperature distribution in multi-layered cooling towers with an inlet temperature of 65°C

The data presented in the table above can be illustrated in a graph depicting the temperature distribution across variations of plates with hole counts of 80, 120, and 185, under an inlet temperature of 65°C. The graph of measurement data at 65°C can be seen in Fig. 6. It can be observed that the final temperature achieved with 80 holes is approximately 49.84°C, while with 120 holes, the final temperature is about 47.06°C. For the configuration with 185 holes, the final temperature reaches approximately 46.22°C.

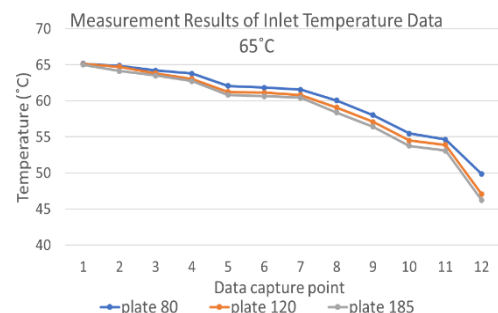


Fig. 6. Measurement data at 65°C

3.2 Temperature distribution in multi-layered cooling towers with an inlet temperature of 75°C

The data presented in the table above can be represented in a graph that illustrates the temperature distribution across variations of plates with hole counts of 80, 120, and 185, under an inlet temperature of 75°C. The graph of measurement data at 75°C can be seen in Fig. 7.

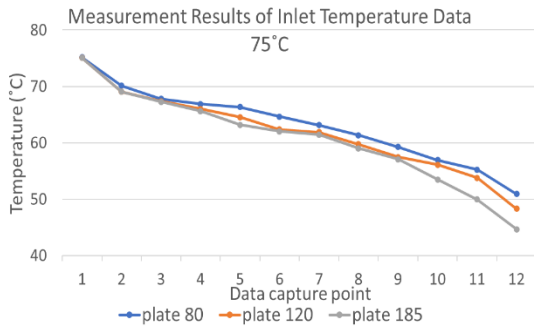


Fig. 7. Measurement data at 75°C

Fig. 7 displays the graph resulting from the temperature measurements conducted at 75°C. The final temperature achieved with 80 holes is approximately 50.9°C, while with 120 holes, the final temperature is about 48.3°C. In the configuration with 185 holes, the final temperature reaches approximately 44.66°C.

3.3 Temperature difference distribution

Here is the calculated data of the temperature difference between the incoming and outgoing water in a multi-stage cooling tower. Fig. 8 illustrates the temperature difference (ΔT) in water when heated at two different temperatures, 65°C and 75°C, across three specific time intervals: 80, 120, and 185 seconds. At each interval, the temperature difference is consistently higher for water heated at 75°C compared to 65°C, indicating a more pronounced temperature increase with higher heating levels. Specifically, at 80 seconds, water heated at 75°C exhibits a 24.28°C rise, while at 65°C, the increase is only 15.32°C. This trend continues at 120 seconds (26.78°C at 75°C vs. 18.06°C at 65°C) and 185 seconds (30.42°C at 75°C vs. 18.8°C at 65°C). These results suggest a direct correlation between the heating temperature and the rate of temperature increase, highlighting the more substantial heat absorption of water at elevated temperatures within the tested intervals.

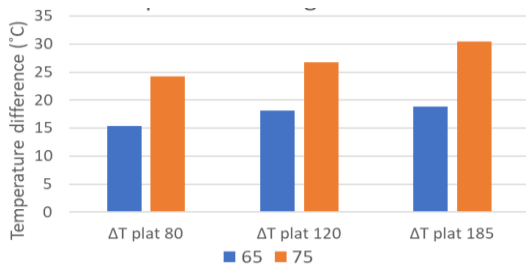


Fig. 8. Temperature difference at various plat

3.4 Heat transfer rate analysis

In analyzing the heat transfer rate emitted from the working fluid in multi-stage cooling towers, it is essential to determine the heat value released, often referred to as the heat transfer rate, calculated using Eq. (1), where Q is heat transfer rate (J/s), \dot{m} is flow rate (Kg/s), C_p is specific heat (Kj/Kg°C), and ΔT is temperature difference (K). By applying Eq. (1) and the measured research data under the specified parameters, the resulting heat transfer rate was determined. The results of the heat transfer rate analysis can be seen in Table 1.

$$Q = \dot{m} \cdot C_p \cdot \Delta T \quad (1)$$

Table 1. Heat transfer rate

Temperature	80 holes	120 holes	185 holes
65°C	419316.6746 W	423299.5071 W	424375.1626 W
75°C	432960.523 W	436599.703 W	441898.349 W

For the plate with 80 holes, the heat transfer rate at an inlet temperature of 65°C was measured at approximately 419,316.67 J/s. However, when the inlet temperature increased to 75°C, the heat transfer rate also rose to around 432,960.52 J/s. This increase suggests that for plates with lower hole counts, a higher inlet temperature may lead to more efficient heat transfer due to the increased energy driving the convective process. This behavior aligns with the principles of thermodynamics, where a greater temperature gradient between the fluid and the plate enhances heat transfer.

The plate with 120 holes exhibited a similar trend. At an inlet temperature of 65°C, the heat transfer rate was approximately 423,299.51 J/s, while an inlet temperature of 75°C resulted in a rate of about 436,599.70 J/s. This slight improvement with increased hole count indicates that additional holes increase the fluid's exposure to the heated surface, thereby enhancing heat transfer rates, even as the fluid temperature rises. Here, both the increase in hole count and temperature contribute positively to heat transfer performance.

For the plate with 185 holes, the highest heat transfer rates were recorded, reaching approximately 424,375.16 J/s at 65°C and 441,898.35 J/s at 75°C. These values suggest that maximizing the hole count not only enhances heat transfer but also leads to more stable rates across varying inlet temperatures. With more holes, the fluid flow is further distributed over the plate, promoting efficient thermal exchange and minimizing losses even at higher temperatures.

Fig. 9 illustrates the highest heat transfer rate occurs at an inlet temperature of 75°C with the maximum hole count of 185 holes. Conversely, the lowest heat transfer rate is observed with a hole count of 80 at an inlet temperature of 65°C.

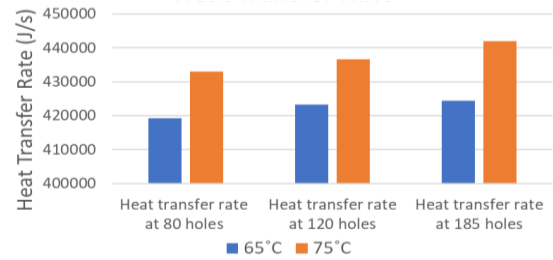


Fig. 9. Heat transfer rate plot

3.5 Convection heat transfer coefficient analysis

To determine the convection heat transfer coefficient using Eq. (2), where h_c is the convection heat transfer coefficient (W/m².K), and A is the surface area (m²). Using Eq. (2) along with the research measurement data and associated parameters, the convective heat transfer coefficient values were obtained. The convection heat transfer coefficient can be seen in Table 2.

$$h_c = \frac{\dot{m} \times C_p \times (T_{in} - T_{out})}{A \times (T_s - T_{\infty})} \quad (2)$$

Table 2. Convection heat transfer coefficient

Temperature	80 holes	120 holes	185 holes
65°C	36727.39 W/m ² K	38046.25 W/m ² K	38787.6 W/m ² K
75°C	34702.54 W/m ² K	36361.08 W/m ² K	38078.81 W/m ² K

For the plate with 80 holes, the convective heat transfer coefficient was approximately 36,727.40 W/m².K at 65°C. However, this value dropped to 34,702.55 W/m².K at the higher inlet temperature of 75°C. This decline suggests that as the inlet temperature increases, the fluid's thermal conductivity may decrease slightly, leading to a lower heat transfer coefficient. This effect could result from changes in fluid properties at elevated temperatures, such as reduced viscosity, which can alter heat transfer dynamics.

For the plate with 120 holes, the convective heat transfer coefficients were 38,046.26 W/m².K at 65°C and 36,361.09 W/m².K

at 75°C, respectively. Although the trend of decreasing heat transfer coefficient with increasing temperature continued, the higher number of holes led to better heat dissipation overall. This suggests that increasing the hole count may offset some of the adverse effects of higher temperatures by enhancing the surface area for heat transfer.

The plate with 185 holes had the highest convective heat transfer coefficients: approximately 38,787.60 W/m²·K at 65°C and 38,078.82 W/m²·K at 75°C. The relatively small decrease in heat transfer coefficient with rising temperature in this configuration indicates that maximizing hole count can effectively counterbalance temperature-induced efficiency drops, possibly due to greater fluid interaction across the surface area. As shown in Fig. 10, the highest heat transfer coefficient value is observed with the maximum hole count of 185 holes. In contrast, the lowest heat transfer coefficient value occurs with a hole count of 80.

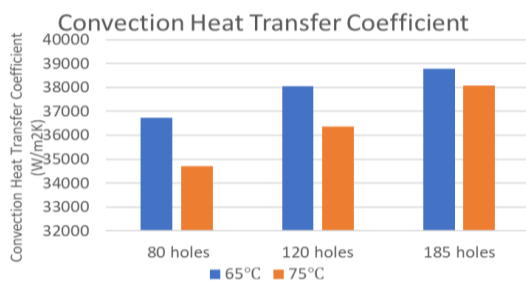


Fig. 10. Convection heat transfer coefficient plot

4 Conclusions

Based on the conducted research, the following conclusions can be drawn:

1. The heat transfer rate and the heat transfer coefficient are optimized at the maximum hole count of 185, with values of approximately 441,898.35 J/s and 38,787.6 W/m²·K, respectively.
2. An increase in the number of holes corresponds to an increase in both the heat transfer rate and the heat transfer coefficient.
3. There is a proportional relationship between the number of holes and the parameters influencing the performance optimization of the cooling tower.

Future research could explore the impact of different hole geometries and arrangements on heat transfer efficiency. Additionally, these findings can be applied in industrial cooling systems to enhance energy efficiency and optimize thermal management in power plants and manufacturing facilities.

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