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Effect Of Numerous Plate Holes In A Cooling Tower On Heat Transfer Optimization

Heli Suansyah, Ahmad Syuhada*, Sarwo Edhy Sofyan
Teknik Mesin, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
*Corresponding author: syuhada_mech@yahoo.com

Abstract

An industry requires a cooling medium to reduce heat in an industrial machine during operation. Companies generally use cooling towers for engine cooling media. The common issue is that heat reduction and heat transfer rate are not significant. Therefore, a new variation is needed to ensure that the cooling tower can effectively lower the temperature of the machinery. The problem statement aims to determine the parameters that can enhance both the heat transfer rate and the heat transfer coefficient in cooling towers. The objective is to determine the heat transfer rate and heat transfer coefficient. The method used is experimental by varying the water inlet in five variations of the cooling tower plates, they are being 48, 60, 80, 120, and 250 holes. The results showed that the highest temperature difference occurs at T_{in} 80°C with the variation of 250 holes, which is 9.34°C, and the highest heat transfer value reached 1833.17 watts. Meanwhile, the lowest temperature difference occurred at T_{in} 60°C with a variation of 48 holes, which is 3.98°C, and the lowest heat transfer value reached 787.47 watts. The highest convection coefficient occurs at T_{in} 70°C with the variation of 250 holes, which is 117.74 W/m²·K. The lowest convection coefficient occurs at T_{in} 80°C with a variation of 48 holes, which is 77.36 W/m²·K. This can be concluded that the temperature difference (ΔT), heat transfer rate, and heat transfer coefficient will increase when the number of holes in each plate variation increases.

Keywords:
Cooling tower, number of holes, temperature difference, heat transfer rate, heat transfer coefficient.

1 Introduction

Cooling towers are essential devices used in industrial systems for water-cooling procedures. They utilize air as their cooling medium to reduce the temperature of water by extracting and dissipating heat into the atmosphere. The heat exchange process allows high-temperature inlet water to cool down, resulting in lowered water outlet temperature.Maintaining the water temperature within certain conditions is crucial for the efficiency of industrial processes. Cooling towers play a vital role in controlling and maintaining water temperature, ensuring optimal performance in industrial systems and equipment. They are critical equipment in the industry for efficient water-cooling processes.

Cooling towers is a heat exchanger used to reduce heat from water to air, resulting in an increase in the temperature and humidity of the liquid [1].Cooling towers are also utilized in efforts to increase the productivity of industrial machines. This is because in several industrial processes, an appropriate level of efficiency and temperature must work optimally [2].

Cooling towers are an essential part of thermal system components. According to the air and water contact modes, cooling towers can be classified into wet cooling towers, dry cooling towers, and hybrid cooling towers. Due to their stable operation and high efficiency, wet cooling towers are widely used in power plants. However, the efficiency of wet cooling towers is less than 60%, and their performance is closely related to the environment, especially in the presence of crosswinds [3].

Cooling towers are one type of cooling system used to cool engine coolant, especially in large quantities. For small engines, usually only a radiator is required as the engine's cooling system. There are two types of cooling towers distinguished based on airflow: natural and mechanical drafts. Natural draft is the airflow that occurs naturally in the cooling tower due to temperature differences in the air. Air naturally flows upwards in the tower due to these temperature differences, which cools the water inside the tower. On the other hand, the mechanical draft is an airflow system that uses fan power or external force to control the airflow. Mechanical Draft can be divided into several types, one of which is Induced Draft, where the airflow is opposite to the direction of the cooled water. This means that the water flows downward from the top of the tower, while the airflow is controlled by fans flowing upward from the bottom of the tower [4].

A heat transfer medium is required in large-scale cooling systems to facilitate the exchange of heat. Common heat transfer mediums include lubricating oil, water, and air [5] [6].

During the cooling process within the cooling tower, a certain amount of cooling water evaporates, leading to a decrease in the flow rate of the cooling water mass. The water lost due to evaporation will be replenished by makeup water [7].

A paper-manufacturing company needs a cooling tower to lower the temperature of a specific machine. The cooling tower has a blower, fan and various tower setups to cool the water. However, this can result in higher operating expenses, even though the evaluation of the cooling tower efficiency is based on the inlet temperature to determine its effectiveness [8].

Navarro and J. Ruiz studied the impact of an inverted tower in a counterflow-parallel flow configuration. By incorporating a fan, the interaction between water and air was enhanced, leading to improved contact. This enhanced contact between water and air promotes efficient heat dissipation [9] [10].

Jamaludinand colleagues conducted an experimental investigation to examine how the decrease in water temperature affects the plastic filler material in the cross-section of a cooling tower [11].Indrawati and colleagues also conducted a study on a small-scale miniature cooling tower for cooling the condenser water in the chemical oxygen demand reflux testing process [12].

The heat transfer rate in cooling towers is relatively low. Therefore, it is necessary to identify parameters that can improve the heat transfer rate and convective coefficient in cooling towers. Based on this background and problem statement, an experimental study is required for a cooling tower by varying the number of holes, hole diameter, and inlet water temperature. The objective is to determine the temperature difference (ΔT), heat transfer rate, and heat transfer coefficient in the cooling tower.

2 Research Methods

The research was conducted at the Laboratory of Thermal Engineering. Start from equipment planning, equipment fabrication, data collection, and data analysis.

2.1 Research Equipment

The designed research equipment is shown in Fig. 1 and consists of two main parts: the internal system and the external system. It includes the components: (1) upper reservoir tank, (2) lower reservoir tank, (3) cooling tower, (4, 5, 6) water pumps, (7) external water reservoir, and (8) gas stove.

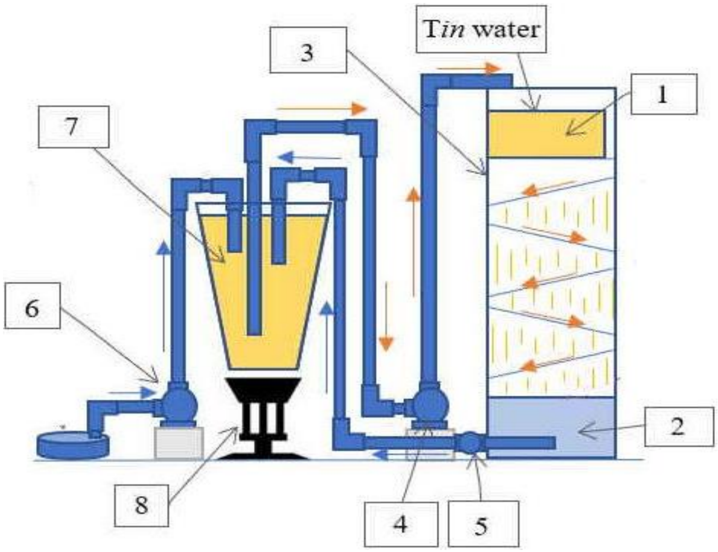

Fig. 1. Research scheme of the cooling tower.

The design of the cooling tower is shown in Fig. 2, with dimensions of length 0.7 m, width 0.5 m, and height 2.4 m. The frame of the cooling tower is made of elbow metal, while the upper and lower reservoir tanks and partition plates are made of aluminum material with a thickness of 0.5 mm. There are 5 racks of partition plates installed in the cooling tower, with 25 racks of partition plates to be tested alternately.

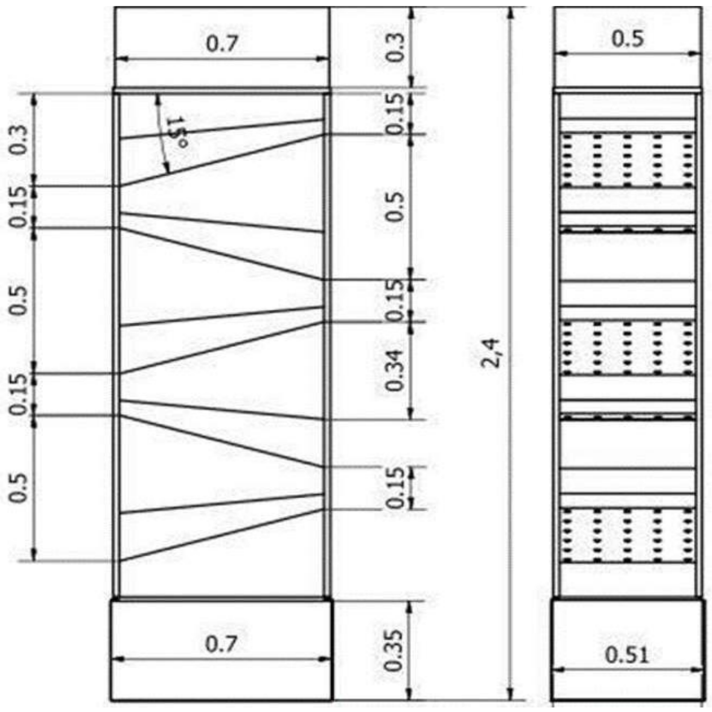

Fig. 2. Cooling tower; dimensions in meters.

The design of the plate can be seen in Fig. 3 with variations in the number of holes: 48, 60, 80, 120, and 250 holes. Each plate has a cross-sectional area of 0.35 m^2 with dimensions of length 0.7 m and width 0.5 m. Table 1 also shows that each variation has a different diameter of the hole.

Table 1. The diameter of holes and number of holes in each plate variation

Plate variation	Diameter of holes	Number of holes
1st Variation	2.5 cm	48
2nd Variation	2.0 cm	60
3rd Variation	1.5 cm	80
4th Variation	1.0 cm	120
5th Variation	0.5 cm	250

*Each variation consists of 5 plates, totaling 25 plates.

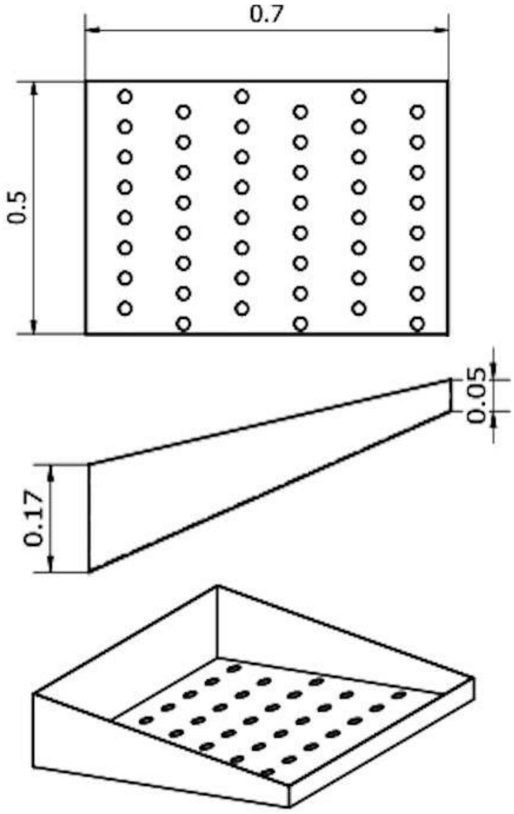

Fig. 3.The design of the plate; dimensions in meters.

The auxiliary tools used for testing the cooling tower are: a gas stove with a gas cylinder, an external water reservoir made of aluminum, 3 water pumps, high-density polyethylene hot water pipes, digital thermometer with a display, stopwatch, and water meter.

2.2 Experimental Testing

The testing is conducted by flowing water from the external water reservoir to the upper reservoir tank, allowing the water to fall through the bottom plates into the lower reservoir tank (Fig. 1). The temperature of the external water reservoir is maintained according to the water inlet temperature variations (T_{in}) by heating the water using a gas stove.

The measurement points on the cooling tower can be seen in Fig. 4, with 12 measurement points labeled as T1 to T12. Data collection was performed for all plate variations, including 48, 60, 80, 120, and 250 holes. Each plate variation was tested with different water inlet temperatures at T1, with variations of T_{in} of 60°C, 70°C, and 80°C.

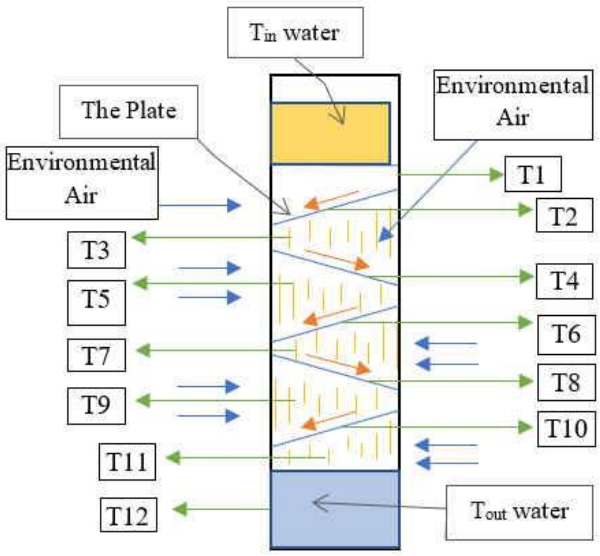

Fig. 4. The measurement points of the digital thermometer on the cooling tower.

These measurement points are used to monitor and analyze the temperature distribution and changes within the cooling tower during the experimental testing.The reasons why we chose 48, 60, 80, 120, and 250 holes in these researches is to determine the highest and lowest temperature difference (ΔT) values in each variation of holes.

Researchers may choose different water inlet temperatures to study the effects of varying conditions on the performance of cooling towers. For instance, they might investigate how different inlet temperatures impact heat transfer rates, cooling efficiency, or the behavior of the cooling tower under varying operational conditions.

For each water inlet temperature (T_{in}) variation, data collection was conducted in 4 stages. In each stage, data are collected every minute for a duration of 5 min. The data collection process for each water inlet temperature variation takes approximately 1 hour. If all plate variations received 15 water inlet temperature variations (T_{in}), the total time required would be more than 15 h.

3 Results and Discussion

The measurements from points T1 to T12 for each water inlet temperature variation (T_{in}) will be processed to determine the highest and lowest temperature difference (ΔT) values. For each plate variation, data calculations will be performed to determine the heat transfer rate and heat transfer coefficient.

3.1 Data Analysis

From the results in Fig. 5, it can be observed that the temperature distribution of T_{in} 60°C in all plate variations decreases on average temperature from 59.83°C to 54.81°C. The most significant temperature drop occurs in the 250-hole plate variation, with a decrease in temperature down to 54.81°C, while the lowest temperature drop occurs in the 48-hole plate variation, reaching only 55.84°C.

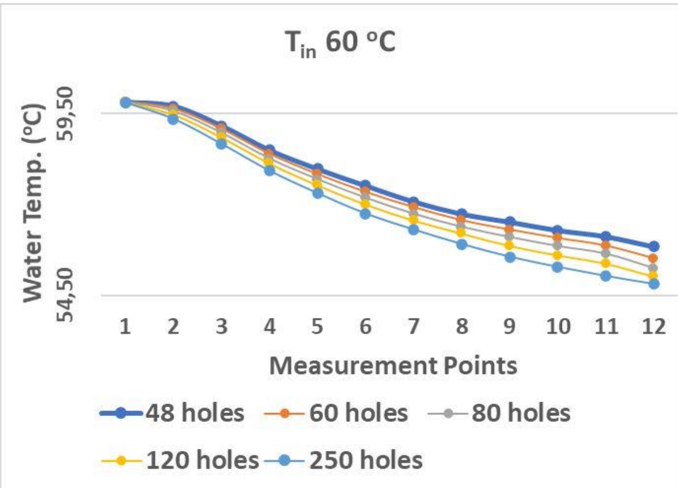

Fig. 5. Distribution temperature T_{in} 60°C.

From the results in Fig. 6, it can be observed that the temperature distribution of T_{in} 70°C in all plate variations decreases on average temperature from 69.83°C to 62.11°C. The most significant temperature drop occurs in the 250-hole plate variation, with a decrease in temperature down to 62.11°C, while the lowest temperature drop occurs in the 48-hole plate variation, reaching only 64.36°C.

From the results in Fig. 7, it can be observed that the temperature distribution of T_{in} 80°C in all plate variations decreases on average temperature from 79.83°C to 70.47°C. The most significant temperature drop occurs in the 250-hole plate variation, with a decrease in temperature down to 70.47°C, while the lowest temperature drop occurs in the 48-hole plate variation, reaching only 73.37°C.

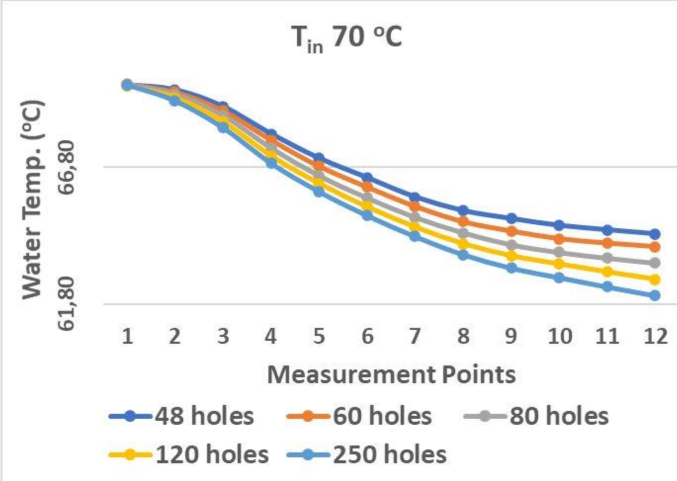

Fig. 6. Distribution temperature T_{in} 70°C.

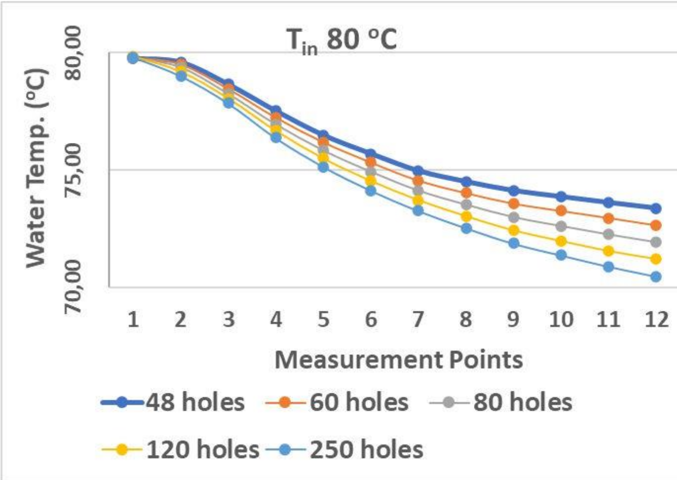

Fig. 7. Distribution temperature T_{in} 80°C.

3.2 Distribution of Temperature Difference

From Fig. 5, Fig.6, and Fig.7, it can be derived that a combined plot in Fig. 8 illustrates the most significant temperature difference (ΔT) occurring at a water inlet temperature of 80°C, which is 9.34°C, with the 250-hole variation. On the other hand, the lowest temperature difference (ΔT) occurs at a water inlet temperature of 60°C, which is 3.98°C, with the 48-hole variation.

In Fig. 8, it is also explained that the variation in water inlet temperature can affect the temperature difference (ΔT) values. The highest temperature difference is observed overall in the variation with an initial water inlet temperature of 80°C. A larger temperature difference between the inlet and outlet water in the cooling tower tends to result in a higher temperature difference. This is because a greater temperature difference provides a higher potential for heat transfer between the water inlet and the cooling medium inside the cooling tower. If the water inlet temperature is higher than the water outlet temperature, the temperature difference tends to be higher. Conversely, if the water inlet temperature is lower than the water outlet temperature, the temperature difference will be lower. The variation in the water inlet temperature plays a crucial role in determining the temperature difference (ΔT) values in the cooling tower.

3.3 Heat Transfer Rate

The heat transfer rate measures the speed or rate at which heat is transferred from one shelf to another at each shelf of the cooling tower.From the calculated data in Fig. 9, it can be observed that the highest heat transfer rate occurs in the plate variation with 250 holes, with an average value of 1005.49 watts. The trend of heat transfer rate shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

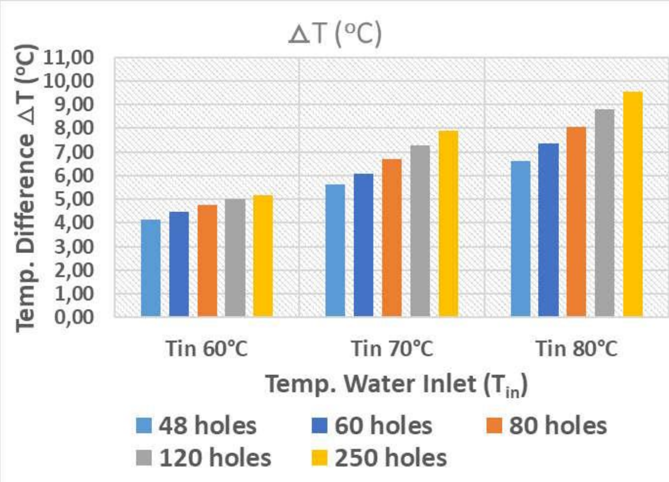

Fig. 8. The effect of the number of plate holes on the temperature difference (ΔT) values in each variation of water inlet temperature (T_{in}).

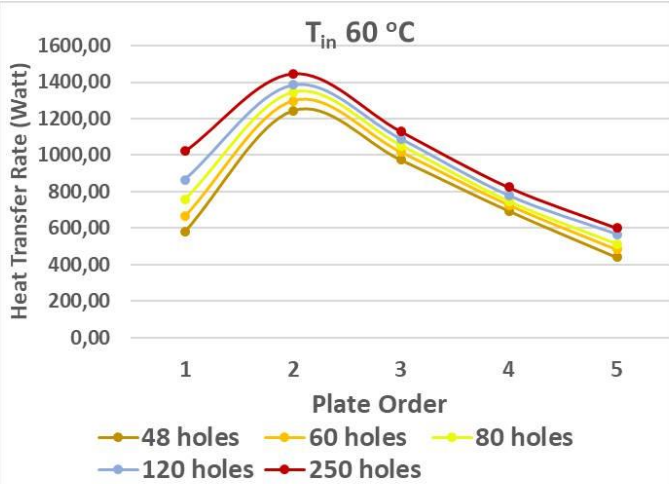

Fig. 9. Distribution of heat transfer rate T_{in} 60°C.

From the calculated data in Fig. 10 it can be observed that the highest heat transfer rate occurs in the plate variation with 250 holes, with an average value of 1532.24 watts. The trend of heat transfer rate shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

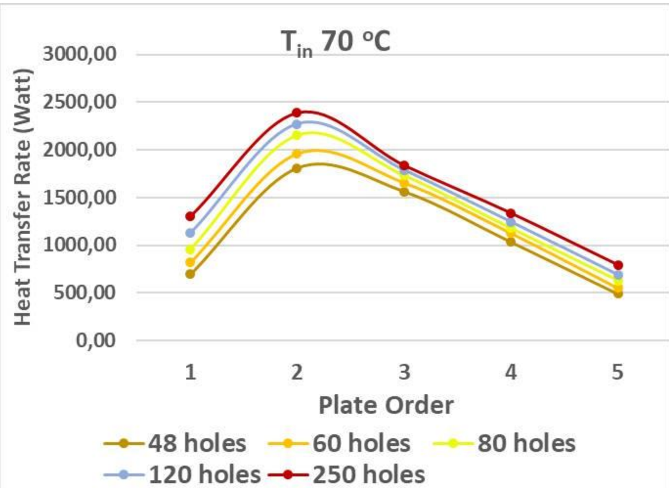

Fig. 10. Distribution of heat transfer rate T_{in} 70°C.

From the calculated data in Fig. 11 it can be observed that the highest heat transfer rate occurs in the plate variation with 250 holes, with an average value of 1833.17 watts. The trend of heat transfer rate shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

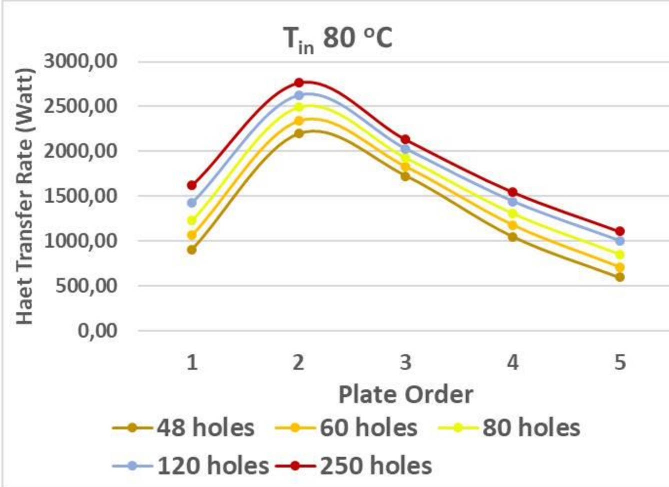

Fig. 11. Distribution of heat transfer rate T_{in} 80°C.

The calculated data from Fig. 9, Fig. 10, and Fig. 11 are summarized in Fig. 12, which illustrates the average heat transfer rates in the cooling tower for all variations of hole numbers at water inlet temperatures of 60°C, 70°C, and 80°C. The average heat transfer rate is highest for the variation of 250 holes in the plates at a water inlet temperature of 80°C, with a value of 1833.17 watts. On the other hand, at a water inlet temperature of 60°C and with a variation of 48 holes in the plates, the average heat transfer rate is the lowest at 787.47 watts.

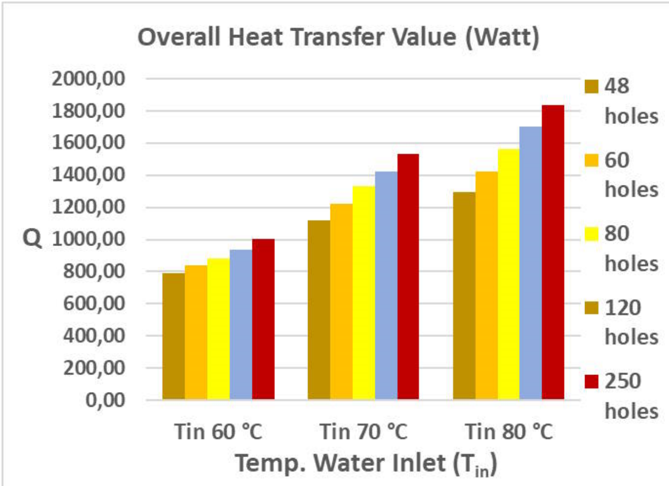

Fig. 12. Overall heat transfer value for each variation of the water inlet temperature (T_{in}).

3.4 Convective Heat Transfer Coefficient

The convective heat transfer coefficient, or simply convective coefficient, describes the efficiency of heat transfer through convection and quantifies the rate at which heat is transferred through convection. The convective coefficient is used to determine the amount of effective heat transferred in a cooling tower.

From the calculated data in Fig. 13, it can be observed that the highest convective heat transfer coefficient occurs in the plate with 250 holes, with an average value of 100.76 W/m²·K. The trend of the convective coefficient shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

From the calculated data in Fig. 14, it can be observed that the highest convective heat transfer coefficient occurs in the plate with 250 holes, with an average value of 117.74 W/m²·K. The trend of the convective coefficient shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

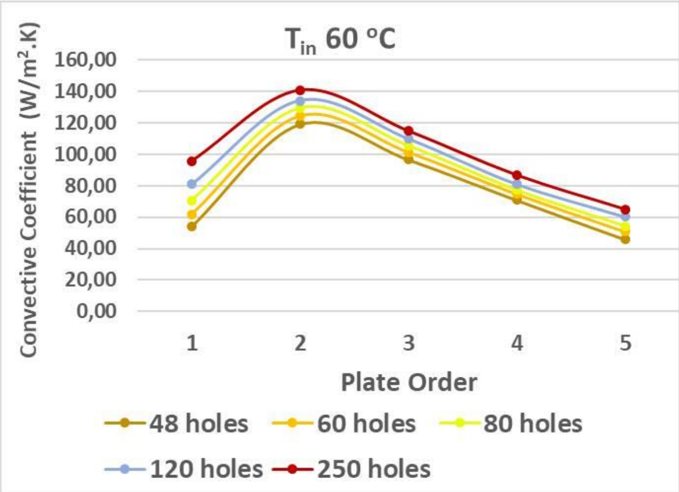

Fig. 13. Distribution of convective coefficient T_{in} 60°C.

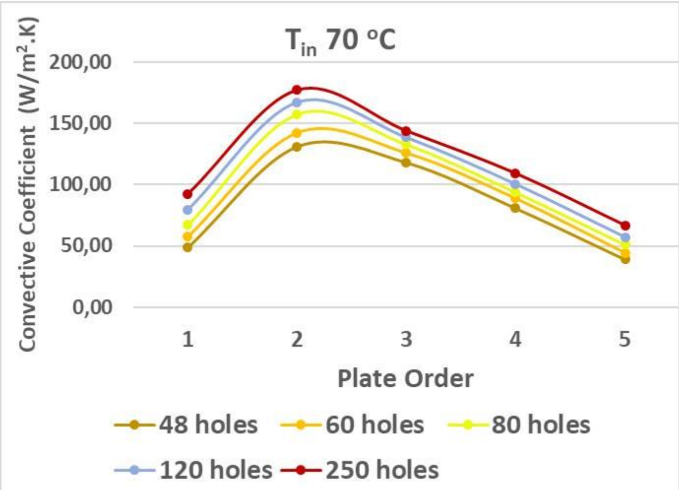

Fig. 14. Distribution of convective coefficient T_{in} 70°C.

From the calculated data in Fig. 15, it can be observed that the highest convective heat transfer coefficient occurs in the plate with 250 holes, with an average value of 112.81 W/m²·K. The trend of the convective coefficient shows an initial increase from the first shelf level to the second shelf level, but then decreases from the second shelf level to the fifth shelf level.

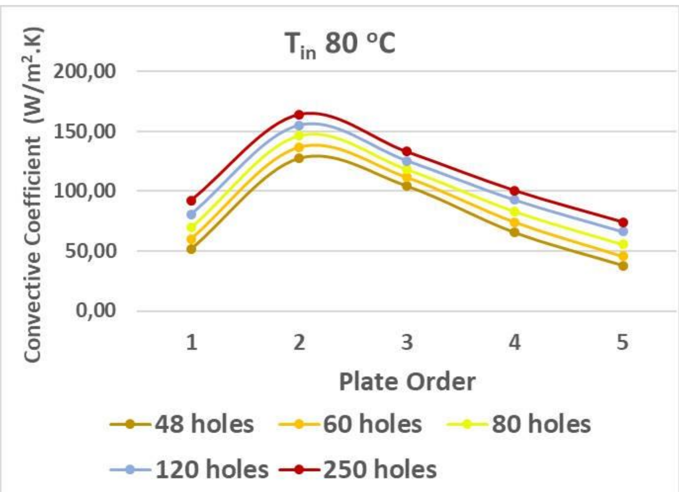

Fig. 15. Distribution of convective coefficient T_{in} 80°C.

The calculated data from Fig. 13, Fig. 14, and Fig. 15 are shown in Fig. 16, which shows the average convective heat transfer coefficients in the cooling tower for all variations of holenumbers at water inlet temperatures of 60°C, 70°C, and 80°C. The highest average convective heat transfer coefficient occurs in the variation with 250 holes at a water inlet temperature of 70°C, with a value of 117.74 W/m²·K. This value is slightly higher compared to the water inlet temperature of 80°C, which is only 112.81 W/m²·K. On the other hand, the lowest average convective heat transfer coefficient occurs in the variation with 48 holes at a water inlet temperature of 80°C, with a value of 77.36 W/m²·K. This value is slightly lower compared to the water inlet temperature of 60°C, which is only 77.41 W/m²·K.

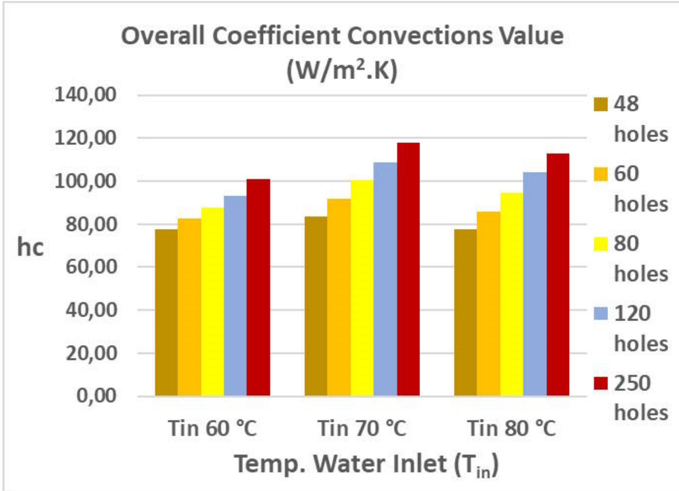

Fig. 16. Overall coefficient convections value for each variation in the water inlet temperature (T_{in}).

4 Conclusion

Based on the research conducted, it can be concluded thatthe highest temperature difference (∆T) value occurs at an inlet water temperature of 80°C, which is equal to 9.34°C, with the plate variation of 250 holes.The highest average heat transfer rate value occurs at an inlet water temperature of 80°C, which is equal to 1833.17 watts, with a plate variation of 250 holes.The highest average convective coefficient value occurs at an inlet water temperature of 70°C, which is equal to 117.74 W/m²·K, with a plate variation of 250 holes.

The values of the temperature difference (∆T), heat transfer rate, and convective coefficient tend to increase as the number of holes in the plate increases. Plates with the highest number of holes can yield higher average values, whereas plates with fewer holes result in lower average values.

Further research is recommended using plates with a larger number of holes to determine the optimal limit of the heat transfer rate and convective coefficient in cooling towers. This would involve exploring different plate variations with increased holedensity. This study identified the maximum efficiency and effectiveness of heat transfer in a cooling tower system.

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