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Experimental study on heat transfer characteristics on intersecting spiral finned tube type on heat exchanger

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Abstract

Compact heat exchangers play an important role in the industrial world, one of their applications being in thermal machines to dissipate heat generated during mechanical processes. To improve the performance of heat exchangers, many studies have been conducted, including the addition of spiral fins, and the spacing of these fins on the outer surface. This study examines the heat transfer characteristics of the outer surface. The heat exchanger is made of galvanized pipe with an inner diameter of 20 mm and an outer diameter of 22 mm. It has a passage length of 300 mm with a sharp turn of 81 mm. The spiral fins are made of aluminium, with a thickness of 0.3 mm, a spial fin height of 10 mm, and a distance of 30 mm between the spiral fins. The cross-section of the spiral fins varies, including options without spiral fins, without spiral fins, without intersecting spiral fins, with intersecting 2 mm spiral fins, intersecting 5 mm spiral fins, and intersecting 7 mm spiral fins. Heat exchanger are supplied with hot at a constant inlet temperature of 80°C and a flow rate of 0.57 kg/s. The fan operates at speeds of 3.59 m/s, 4.45 m/s and 5.07 m/s. The results show that the highest heat transfer rate and heat transfer coefficient are produced by the heat exchanger with a cross-section of 5 mm intersecting spiral fins, specifically 11,682.7 W and 604 W/m^2.K.

Keywords:
Compact heat exchanger, heat transfer characteristics, intersecting spiral fins.

1 Introduction

Energy is very important for industrial development, particularly in the area of energy saving, not only in Indonesia, but also around the world. The economic utilization of energy is one way address energy problems. In the industrial sector, the utilization of heat, whether generated or waste heat cannot be overlooked. One significant source of heat is thermal engines.

Thermal engine produce heat as a by-product of their operation. When the heat generated by the thermal engine is not managed properly, it can lead to overheating, causing the components to become fatigued and damaged. This can adversely affect engine performance and even lead to operational failure. Therefore, it is essential to manage the heat in the thermal engine to maintain performance and prevent component deterioration. The heat from the thermal engine must be discharged into a thermal reservoir (such as the sea, lake river or air) using a heat exchanger.

The use of heat exchanger devices in thermal engines plays an important role in the cooling system by reducing temperature. The most commonly used design is the circular tube, which facilitates the flow of hot, high-pressure fluid through the heat exchanger. In cooling systems, Compact Heat Exchangers (CHE) are employed for thermal engines due to their large heat transfer surface area ratio, optimizing the heat transfer rate that occurs. Many heat exchanger devices are found in industries such as manufacturing, power generation, transportation, air conditioning, cryogenics, and heat recovery [1-3].

The large amount of heat be disposed of in a thermal machine requires a heat exchanger with a high heat transfer coefficient (hc). The heat transfer coefficient is influenced by several variables such as pipe material selection, pipe length, width, flow type, and fin shape [4-6].

The heat transfer process is dominated by convection and conduction. Non-dimensional numbers that affect heat transfer include the Reynolds number, Nusselt number and Prandtl number. These values depend on fluid properties such as density, viscosity, thermal conductivity, specific heat, and flow [7].

Galvanized pipe is more resistant to corrosion than other iron or steel options. Galvanized pipe is widely used because of its two protective properties. As a protective coating, galvanized pipe creates a hard, metal-bonded layer of zinc that covers the entire surface of the steel and protects it from environmental attack. In addition, the sacrificial anode, made of zinc, protects the steel from damage and enhances its resistance to corrosion [8].

Various efforts have been made and developed by previous studies to improve the performance of heat exchangers. The number of turns affects the value of the convective heat transfer coefficient, with turbulent flow occurring in the area of turns 10 to 16 times the tube diameter [9]. Increasing the turbulence flow pattern can increase the value of the heat transfer coefficient and inhibit the fluid flow rate [10]. The performance of the heat exchanger is influenced by the distance, number and design of baffles, which can reduce the pressure [11]. The optimum heat transfer coefficient and pressure drop are influenced by parameters such as tube layout, tube pitch, baffle shape and distance, and flow velocity [12]. The addition of fins on the outer surface can increase the heat transfer rate and convection heat transfer coefficient [13]. Increasing the Reynold number will affect the efficiency and heat transfer coefficient [14]. The higher the heat transfer coefficient, the effectiveness and fouling factor tend to decrease as fluid flow increases [15]. The effect of annular fin shape variation, in clouding concentric circular finned tubes, eccentric circular finned tubes, hollow circular finned tubes, serrated circular finned tubes, and star-shaped finned tubes, has been studied previously [16].

Based on previous literature many studies have been conducted including sharp turn technology, spiral fin addition, and spiral fin spacing on the outer surface of the Compact Heat Exchanger (CHE) [9-10], [13]. This study aims to assess the heat transfer rate and heat transfer coefficient on the outer surface of a Compact Heat Exchanger (CHE). The cross-section of spiral fins that are varied intersect on the Compact Heat Exchanger (CHE) tool namely without spiral fins, without intersecting spiral fins, intersecting 2 mm spiral fins, intersecting 5 mm spiral fins and intersecting 7 mm spiral fins.

2 Research Methods

2.1 Research Design

Showing the steps taken in this research as shown in Fig. 1.

2.2 Design of Heat Exchanger

In this research, a tube-type heat exchanger was constructed using SCH-40 galvanized pipe, which has an inner diameter of 20 mm and an outer diameter of 22 mm. The total length of the heat exchanger is 6 m, with a passage length of 300 mm and a tube turn of 81 mm. The fins used are aluminium, with a thickness of 0.3 mm, a spiral fin height of 10 mm, and a distance of 30 mm between the spiral fins. The heat exchanger design as shown in Fig. 2.

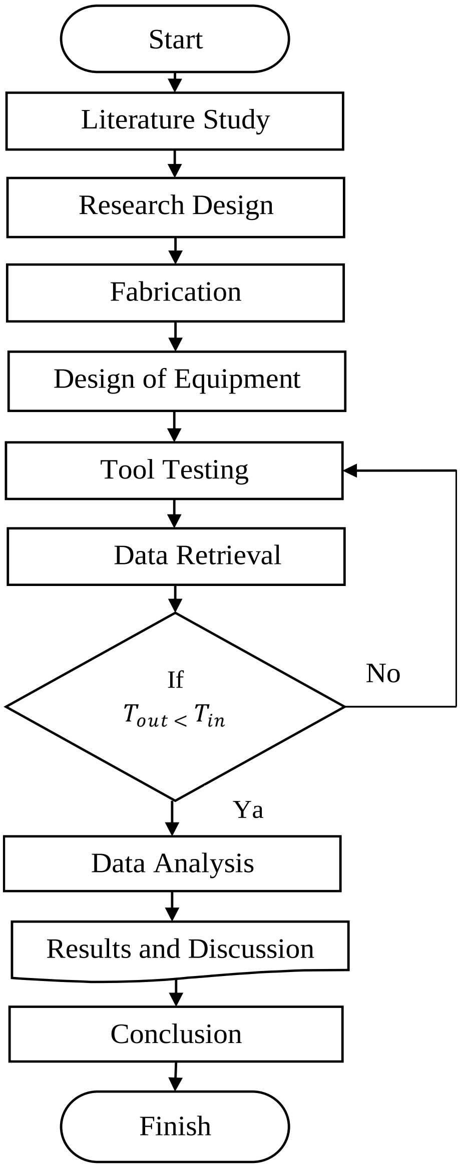


Fig. 1. Flowchart.

In this study, the heat exchanger tool consists of 5 tools with the same diameter, passage length, tube turns, spiral fin thickness, spiral fin height, and spiral fin spacing design size as Fig. 2, which distinguishes the configuration of the cross-section of the spiral fins that are varied intersected, namely (a) without spiral fins (b) without intersecting spiral fins (c) pieces of 2 mm spiral fins (d) intersecting 5 mm spiral fins (e) intersecting 7 mm spiral fins. The configuration of intersecting spiral fins as shown in Fig. 3.

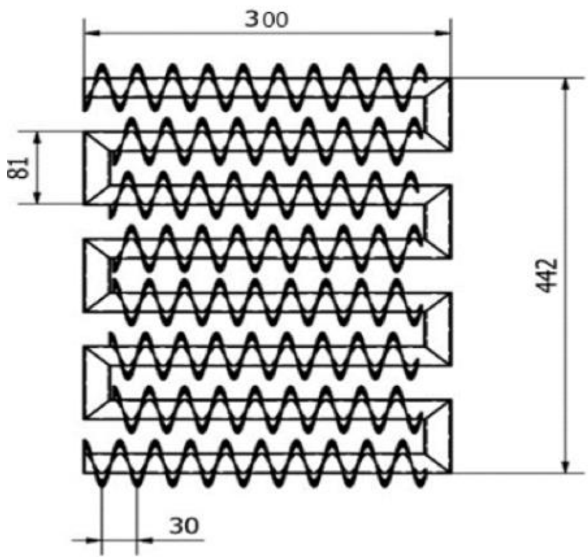
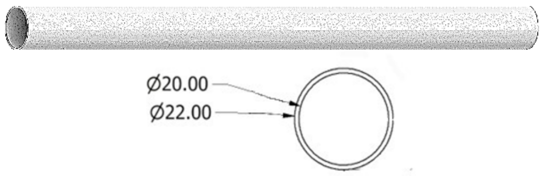
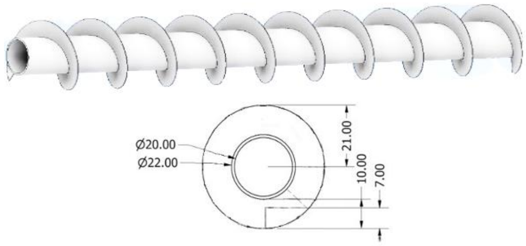


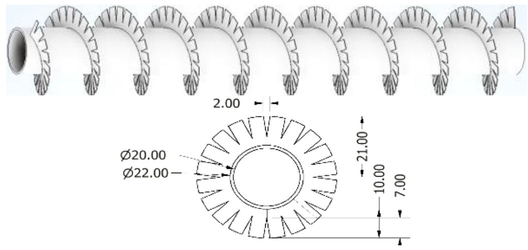
Fig. 2. Design of heat exchanger.



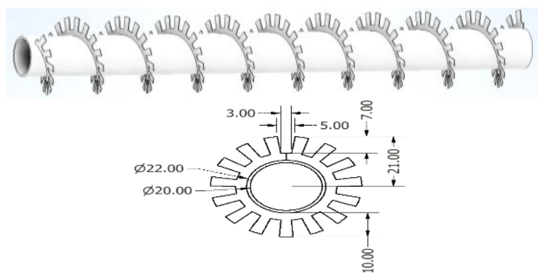
(a) Without spiral fins



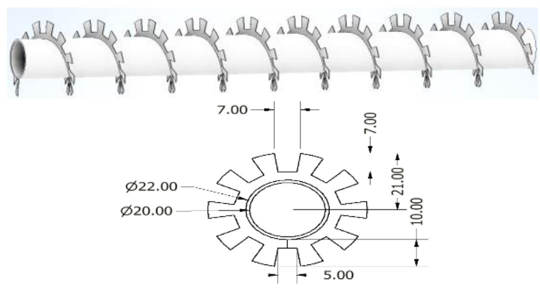
(b) Without intersecting spiral fins



(c) Intersecting 2 mm spiral fins



(d) Intersecting 5 mm spiral fins



(e) Intersecting 7 mm spiral fins

Fig. 3. The configuration of intersecting spiral fins.

2.3 Schematic of Research

In this study, an experimental method was used to determine the effect of a treatment on other variables under specified conditions. The variables examined affect the temperature of the fluid in relation to the variation of intersecting spiral fins, as shown in Fig. 3. The first step in testing the heat exchanger tool is to provide hot water and cold water as the working fluids to be tested in the reservoir. During the testing of the heat exchanger tool, data collection for the test equipment is conducted gradually, one by one. For each piece of test equipment, three experiments were performed with the same inlet temperature of 80ºC. The water is heated using a heater to a temperature of 80ºC. The hot fluid is distributed by the pump into the inlet of the heat exchanger, and the fluid exits through the outlet of the heat exchanger. The hot fluid is then collected back in the original hot water reservoir to maintain its temperature. The cold fluid is accommodated in a tube that surrounds the heat exchanger tool. The temperature of the cold fluid is kept below 30ºC by a continuously flowing water in and out of the tube. Inlet and outlet water temperatures are measured by placing thermocouples at the inlet and outlet of the heat exchanger. The temperature of the air is measured by placing a thermocouple at the front of the fan and another at the back of the heat exchanger box, 55 cm from the heat exchanger. The fan is positioned in front of the heat exchanger box at the same distance of 55 cm. Different wind speeds are categorized as slow (3.59 m/s), medium (4.45 m/s), and high (5.07 m/s), with measurements taken using a thermocouple before testing. Data collection is conducted at several predetermined thermocouple points, and the average values are recorded. Data collection occurs every 2 minutes, with a total collection time of 10 minutes for each air speed. The schematic of the test equipment as shown in Fig. 4.

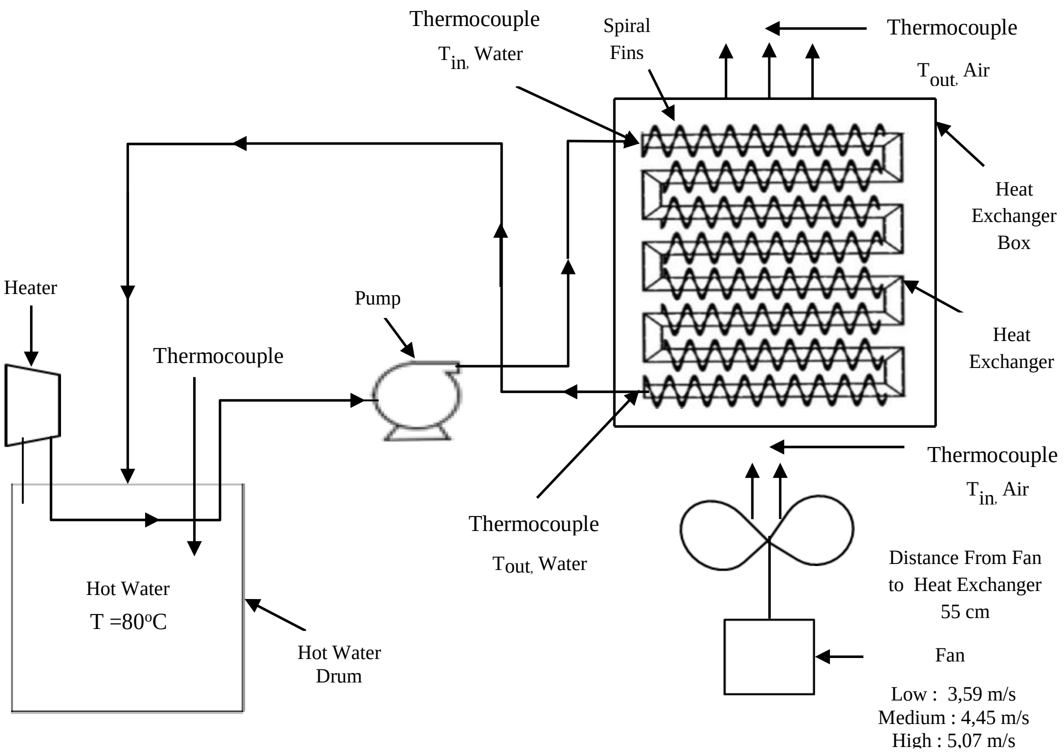


Fig. 4. Schematic of the research test apparatus.

2.4 Data Analysis

To get the convection heat transfer coefficient, we must first get the mass flow rate and heat transfer rate. The steps are:

1. Mass flow rate of water [7] (Eq. 1)

$$\dot{m} = \rho \cdot A \cdot v \quad (1)$$

Where $\dot{m}$ is the mass flow rate of water (kg/s), ρ is the density of water (kg/m^3), v is the velocity of water (m/s). Where ρ (water density) 994.75 kg/m^3.

2. Heat transfer rate [7] (Eq. 2)

$$q = \dot{m} \cdot C_p \cdot \Delta T \quad (2)$$

Where q is the heat transfer rate (W), $\dot{m}$ is the mass flow rate of water (kg/s), C_p is the specific heat of water (J/kg.K), ΔT is the temperature difference of *inlet* water and *outlet* water (K). Where C_p (specific heat of water) 4200 J/kg.K.

3. Heat transfer coefficient [7] (Eq. 3)

$$hc = \frac{q}{A \cdot \Delta T_{lmtd}} \quad (3)$$

Where hc is the overall heat transfer coefficient (W/m^2.K), q is the heat transfer rate (W), A is the area of the heat transfer field (m^2), ΔT_{lmtd} is the log mean temperature difference.

3 Results and Discussion

3.1 Temperature Distribution

The test data is displayed in a graph. The graph is at an inlet temperature of 80°C. The graph is plotted with the temperature distribution against time. Data is taken every 2 minutes increment with a data collection period of 10 minutes.

Fig. 5 shows the temperature distribution graph at an air velocity of 5.07 m/s for each configuration of intersecting spiral fins on the heat exchanger. The 5 mm intersecting spiral fin heat exchanger experienced an average temperature decrease of 4.9%. The 2 mm intersecting spiral fin heat exchanger experienced an average temperature drop of 4.4%. The 7 mm intersecting spiral fin heat exchanger experienced an average temperature drop of 3.9%. So the heat exchanger with intersecting spiral fins of 5 mm experienced a higher temperature drop than the heat exchanger with intersecting spiral fins of 2 mm, 7 mm, without intersecting and withous spiral fins.

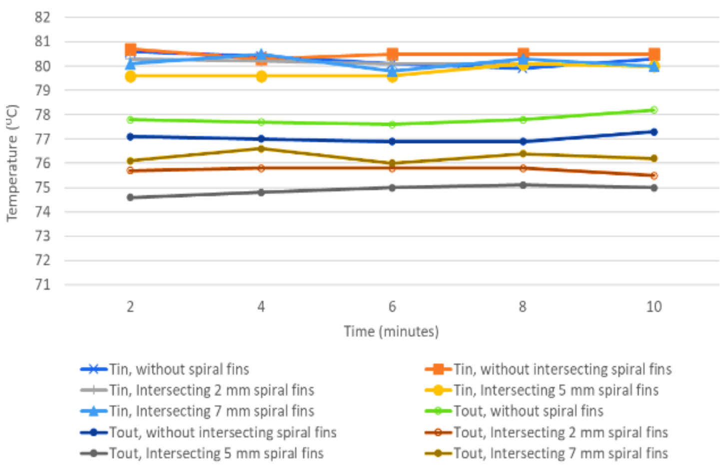


Fig. 5. Temperature distribution at air velocity 5.07 m/s in spiral fin intersecting configuration of the heat exchanger.

Fig. 6 shows a graph of the effect of air velocity on temperature distribution with intersecting 5 mm spiral fins on the heat exchanger. At an air velocity of 5.07 m/s, there was an average temperature drop of 4.9%. At an air velocity of 4.45 m/s, the average temperature drop was 4.6%. At an air velocity of 3.59 m/s, the average temperature drop was 4.2%. Therefore, the heat exchanger with an air velocity of 5.07 m/s experienced a greater decrease than at air velocities of 4.45 m/s and 3.59 m/s.

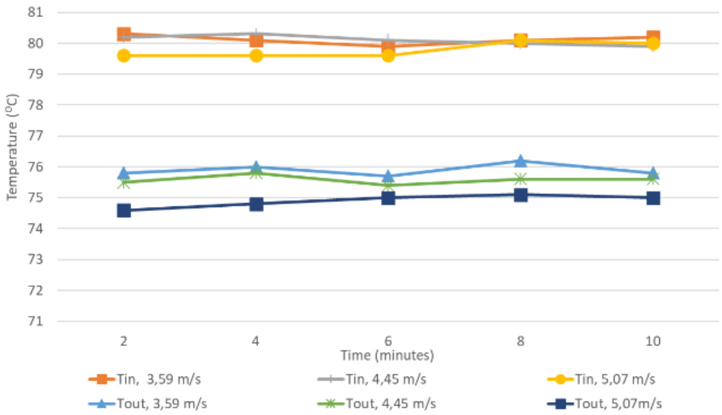


Fig. 6. Effect of air velocity on temperature distribution with intersecting 5 mm spiral fins on heat exchanger.

3.2 Heat Transfer Rate

The results of the heat transfer rate using Eq. 2. The result data is displayed in a graph of the effect of intersecting spiral fins on the heat transfer rate in the heat exchanger.

Fig. 7 shows a graph of the heat transfer rate at an air velocity of 3.59 m/s for each configuration of intersecting spiral fins on the heat exchanger. In the heat exchanger without spiral fins the average heat transfer rate is 3830.4 W. In the spiral fin heat exchanger without intersecting the average heat transfer rate is 5745.6 W. In the 2 mm intersecting spiral fin heat exchanger the average heat transfer rate is 8618.4 W. In the 5 mm intersecting spiral fin heat exchanger the average heat transfer rate is 10102.7 W. In the 7 mm intersecting spiral fin heat exchanger the average heat transfer rate is 7277.8 W.

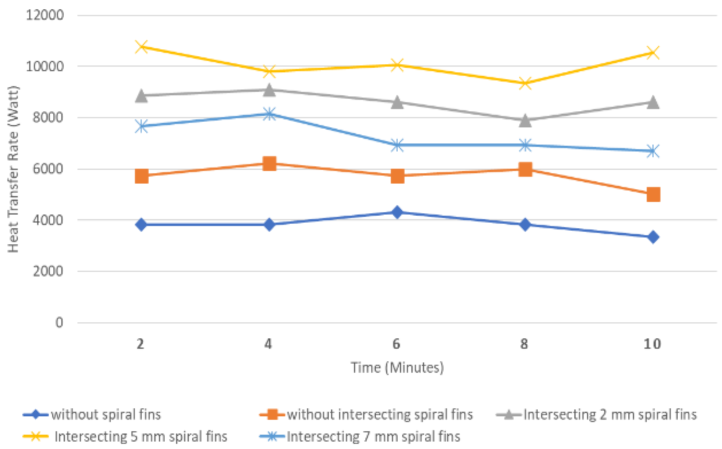


Fig. 7. Effect of intersecting spiral fins on heat transfer rate in heat exchanger with air velocity of 3.59 m/s.

Fig. 8 shows a graph of the heat transfer rate at an air velocity of 4.45 m/s for each configuration of intersecting spiral fins on the heat exchanger. In the heat exchanger without spiral fins the average heat transfer rate is 4596.5 W. In the spiral fin heat exchanger without intersecting the average heat transfer rate is 6655.3 W. In the 2 mm intersecting spiral fin heat exchanger the average heat transfer rate is 9336.6 W. In the 5 mm intersecting spiral fin heat exchanger the average heat transfer rate is 11012.4 W. In the 7 mm intersecting spiral fin heat exchanger the average heat transfer rate is 7996.0 W.

Fig. 9 shows a graph of the heat transfer rate at an air velocity of 5.07 m/s for each configuration of intersecting spiral fins on the heat exchanger. In the heat exchanger without spiral fins the average heat transfer rate is 5841.4 W. In the spiral fin heat exchanger without intersecting the average heat transfer rate is 8283.2 W. In the 2 mm intersecting spiral fin heat exchanger the average heat transfer rate is 10581.5 W. In the 5 mm intersecting spiral fin heat exchanger the average heat transfer rate is 11682.7 W. In the 7 mm intersecting spiral fin heat exchanger the average heat transfer rate is 9288.7 W.

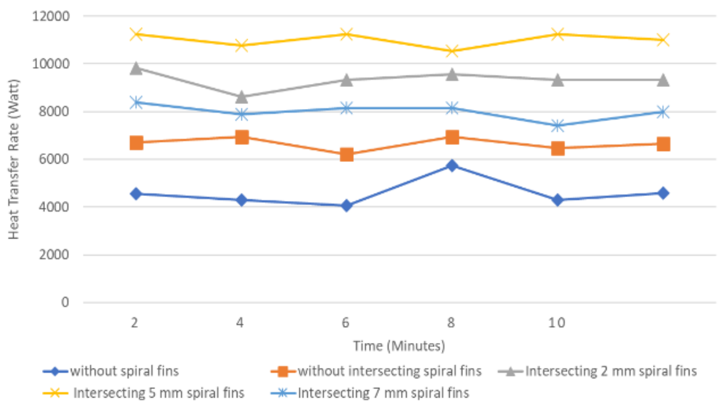


Fig. 8. Effect of intersecting spiral fins on heat transfer rate in heat exchanger with air velocity 4.45 m/s.

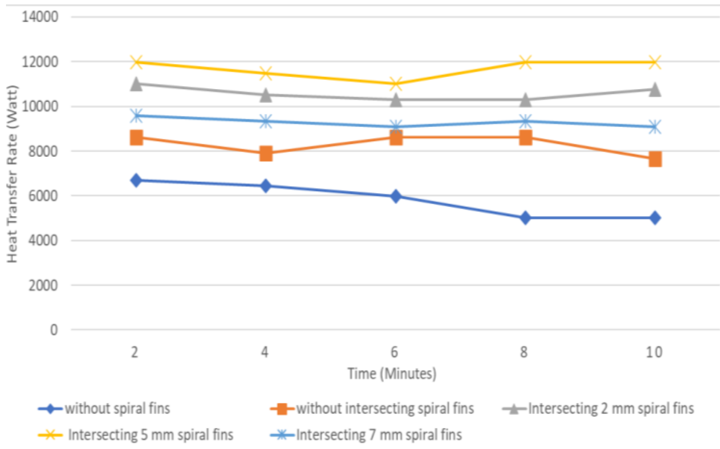


Fig. 9. Effect of intersecting spiral fins on heat transfer rate in heat exchanger with air velocity of 5.07 m/s.

Fig. 10 shows the graph of heat transfer rate with intersecting 5 mm spiral fins on the heat exchanger. At an air velocity of 3.58 m/s the average heat transfer rate is 10102.7 W. At an air velocity of 4.45 m/s the average heat transfer rate is 11012.4 W. At an air velocity of 5.07 m/s the average heat transfer rate is 11682.7 W. Then the heat exchanger with an air velocity of 5.07 m/s experiences a higher heat transfer rate than the air velocity of 4.45 m/s and 3.59 m/s.

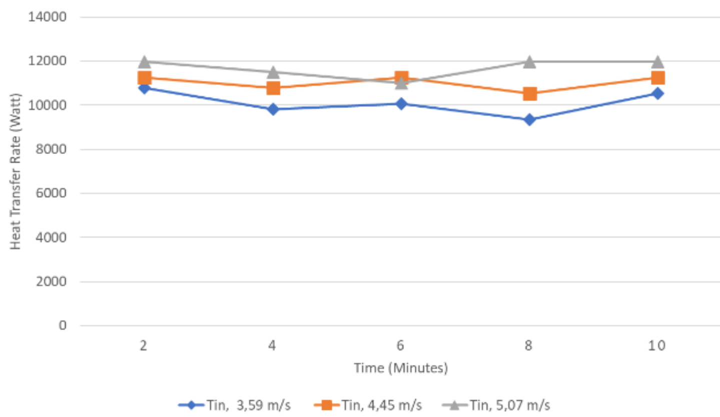


Fig. 10. Effect of air velocity on heat transfer rate of intersecting 5 mm spiral fins on heat exchanger.

3.3 Heat Transfer Coefficient

The results of the heat transfer coefficient using Eq. 3. The result data is displayed in a graph of the effect of intersecting spiral fins on the heat transfer coefficient in the heat exchanger.

Fig. 11 shows a graph of the average heat transfer coefficient of each configuration of intersecting spiral fins on the heat exchanger. In the heat exchanger without spiral fins, the average heat transfer coefficient at an air velocity of 3.59 m/s is 195 W/m^2.K, at an air velocity of 4.45 m/s by 234 W/m^2.K and at an air velocity of 5.07 m/s of 297 W/m^2.K. In the heat exchanger without intersecting spiral fins, the average heat transfer coefficient at an air velocity of 3.59 m/s is 293 W/m^2.K, at an air velocity of 4.45 m/s by 339 W/m^2.K and at an air velocity of 5.07 m/s of 422 W/m^2.K. In the heat exchanger intersected by 2 mm spiral fins, the average heat transfer coefficient at an air velocity of 3.59 m/s is 441 W/m^2.K, at an air velocity of 4.45 m/s by 478 W/m^2.K and at an air velocity of 5.07 m/s of 544 W/m^2.K. In the heat exchanger intersected by 5 mm spiral fins, the average heat transfer coefficient at an air velocity of 3.59 m/s is 520 W/m^2.K, at an air velocity of 4.45 m/s by 568 W/m^2.K and at an air velocity of 5.07 m/s of 604 W/m^2.K. In the heat exchanger intersected by 7 mm spiral fins, the average heat transfer coefficient at an air speed of 3.59 m/s is 372 W/m^2.K, at an air velocity of 4.45 m/s by 408 W/m^2.K and at an air velocity of 5.07 m/s of 475 W/m^2.K.

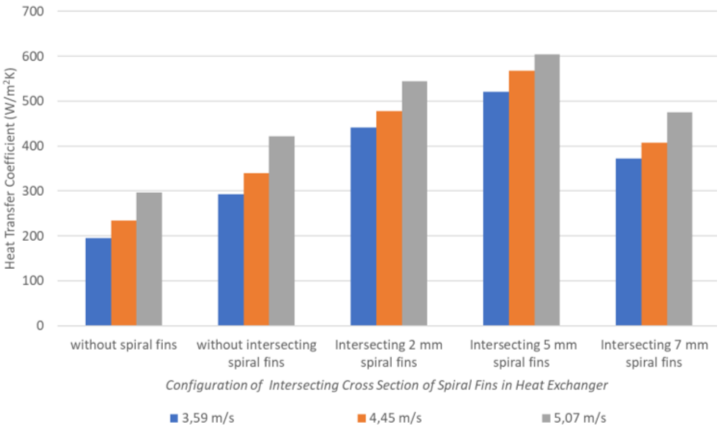


Fig. 11. Effect of intersecting spiral fins on heat transfer coefficient in heat exchanger with air velocity 3.59 m/s, 4.45 m/s, 5.07 m/s.

Then, the heat transfer coefficient is influenced by the air velocity and temperature difference. The greater the air velocity, the higher the heat transfer coefficient. This is because air affects the Reynolds number, as the air speed, increases, the Reynolds number also increases. A large Reynolds number results in greater flow turbulence. Turbulence is one of the factors that affect the heat transfer coefficient, so the heat transfer coefficient increases as the turbulence of the flow increases. The fluid flow across the intersecting configuration of spiral fins on the heat exchanger tends to be turbulent.

4 Conclusion

A heat exchanger with an intersecting spiral fin cross section of 5 mm produces the highest heat transfer rate and heat transfer coefficient. This is due to the turbulence created by the air flow passing through the intersecting spiral fin cross section. The greater the air velocity across the surface of the intersecting spiral fins in the heat exchanger, the higher the heat transfer rate and heat transfer coefficient.

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