Heat Transfer Analysis on the Tube Type Heat Exchanger with Fin Pitch Variations

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Abstract. A heat exchanger is a device usually used to dissipate the heat generated during the mechanical processes. To improve the performance of the heat exchanger, a lot of research has been conducted including the addition of fins on the outer surface. This experimental study examines the heat transfer process on the outer surface of the heat exchanger. The heat exchanger was made of galvanized pipes with an inner and outer diameter of 20 mm and 22 mm. The heat exchanger has a pass length of 30 cm, the spacing between the tube of 6 cm and a total length of 6 m. The spiral fin made of an aluminum plate is mounted to the outer surface of the tube pipe of the heat exchanger. It has a thickness of 0.3 mm. The fin pitch of the heat exchangers was varied to 3 cm, 5 cm, and 7 cm. The heat exchanger was fed with hot water at a constant temperature of 80 °C and a flow rate of 0.4 L/s. While, the ambient air was blown at the outer surface of the heat exchanger at three different speeds namely 2.4 m/s, 2.8 m/s, and 3.4 m/s. It is found that the highest convective heat transfer rate and convective heat transfer coefficient are yielded by the heat exchanger with a fin pitch of 3 cm namely, 6607.2 W and 235.8 W/m²K, respectively.

1. Introduction
Heat exchangers are a device used to transfer thermal energy between two or more fluids at different temperatures. Heat exchangers are not only used in power generation, petroleum, transportation, cooling (air conditioner, cryogenic, and heat recovery), and manufacturing industries processes, but they also function as key components of many industrial products that available in the market.

Heat exchangers can be classified based on the heat transfer process, amount of fluid involved, and heat transfer mechanism. Heat exchangers can also be classified according to the area of the heat transfer contact. One type of heat exchanger that is commonly used is a compact heat exchanger. Compact heat exchangers have a very high heat transfer surface area to volume ratio and related to their heat transfer coefficient.

The convection heat transfer coefficient (h) greatly influences the heat exchanger performance. The value of the heat transfer coefficient and heat transfer rate in heat exchangers is influenced by the length of the tube, the width of the heat transfer area, and also the type of flow. In the turbulent flow type, the more turbulent flow is, the greater the heat transfer coefficient is attained [1].

The turbulent regime of the working fluid flowing inside the tube might be triggered by creating sharp turns on the heat exchanger. Besides, increasing the flow rate of the working fluid inside the tube induces the Reynolds number to increase and leads the turbulent regime to expand. Introducing fins on the inner surface of the heat exchanger’s tube can also generate the turbulent regime of the working fluid. The turbulence regime of the working fluid on the outer surface of the tube can be
generated by increasing the flow rate of ambient air crossing through the tube. The addition of fins to the outer surface of the tube also causes turbulence of the airflow to increase [2-5].

Studies on convective heat transfer on the flow inside the pipe with a sharp turn tube have been carried out by Ferianto et al., [6]. Carija et al., [7] analysed the heat transfer on the airsides of the flat finned tube and louvered fin heat exchangers. The characteristics of heat transfer of a turbulent flow of a finned heat exchanger with staggered arrangements have been investigated by Bhuiyan et al., [8]. The heat transfer characteristics of finned tube heat exchangers with several types of fins (plain, louvered, slit, wavy, annular, longitudinal, and serrated fins) were presented by several researchers [9-10]. Gholami et al., [11] examined the heat transfer rate in corrugated tubes and fins.

This study aims to examine the heat transfer rate and the coefficient of the convective heat transfer on the outer surface of a tube-type compact heat exchanger with a sharp turn. The experiment was conducted considering different fin arrangements namely a finless heat exchanger, a heat exchanger with a varied fin pitch of 3 cm, 5 cm and 7 cm.

2. Methodology
2.1. Experimental set up
The heat exchanger (HE) used in this experiment was made of SCH-40 galvanized pipe which has inner and outer diameters are 22 mm 20 mm, respectively. The heat exchanger as a pass length of 30 cm, a tube’s spacing of 6 cm and a total length of 6 m. A spiral fin made of aluminum was attached to the outer surface of the tube. The fin has a thickness of 0.3 mm and a height of 10 mm. In this study, four configurations of the heat exchanger were examined including finless, fin pitch 3 cm, fin pitch 5 cm, and fin pitch 7 cm (See Figure 1). Other equipment used includes thermocouple, digital thermometer, fan, hot water drum, hot water inlet pipe, hot water outlet pipe, heater and pump, and stopwatch.

![Figure 1. Heat exchanger configuration (a) finless, (b) heat exchanger with fin pitch 3 cm, (c) heat exchanger with fin pitch 5 cm, (d) heat exchanger with fin pitch 7 cm.](image)

This research was carried out by flowing the hot water into the tube of the heat exchanger. An integrated water heater-pump was used to heat up and to circulate the water into the heat exchanger at a constant temperature of 80 °C and a flow rate of 0.4 L/s. Thermocouples are placed at the inlet and outlet of the heat exchanger to measure the water temperature. A fan placed in front of the heat exchanger was used to circulate the ambient air to the outer surface of the heat exchanger. The air velocity is varied as 2.4 m/s, 2.8 m/s, and 3.4 m/s for each configuration of the heat exchanger (See Fig. 1). Air temperature is measured by placing the thermocouple on the front of the fan and the back of the heat exchanger(10 cm distance from the heat exchanger). Each experiment was conducted for 40 minutes and data was recorded every 5 minutes. The schematic of the test rig is illustrated in Figure 2.
2.2. Heat transfer rate
The rate of heat dissipated by the heat exchanger is calculated as given by Equation 1:

\[ Q = \dot{m} \cdot C_p \cdot \Delta T \]  

(1)

Where \( Q \) is the heat transfer rate (W), \( \dot{m} \) is the mass flow rate of circulating water (kg/s), \( C_p \) is the water specific heat (J/kgK), and \( \Delta T \) is the water temperature difference between inlet and outlet (K).

2.3. Convective heat transfer coefficient
The coefficient of the convective heat transfer on the airside of the heat exchanger is given as follows:

\[ h = \frac{Q}{A \cdot \Delta T} \]  

(2)

Where \( h \) is the convective heat transfer coefficient (W/m\(^2\)K), \( Q \) is the heat transfer rate (W), \( A \) is the heat transfer area (m\(^2\)), and \( \Delta T \) is the temperature difference (K), presented by equation 3.

\[ \Delta T = T_s - T_\infty \]  

(3)

Where \( T_s \) is the surface temperature of the heat exchanger (K) and \( T_\infty \) is the ambient air temperature (K).

In this study, the gradient temperature that occurs in the heat exchanger’s pipe wall is ignored. The surface temperature of the heat exchanger is assumed the same as the average temperature of the circulating water as given by equation 4.

\[ T_s = \frac{T_{\text{in,water}} + T_{\text{out,water}}}{2} \]  

(4)

Where \( T_{\text{in,water}} \) is the inlet water temperature (K) and \( T_{\text{out,water}} \) is the outlet water temperature (K).

3. Results and discussion
3.1. Temperature distribution
Figure 3 shows the water temperature distribution for each configuration of the heat exchanger at an air flow of 3.4 m/s. From the experiment, it is found that the outlet water temperature of the finless heat exchanger reduces at an average value of 3.1%. The results reveal that the outlet water temperatures are lower when the spiral fin is introduced to the heat exchanger. This is due to the heat transfer area of the heat exchanger increases. It is found that the outlet water temperatures of the heat exchanger reduced by 4.6 %, 4.8%, and 5% for those with a fin pitch of 7 cm, 5 cm, and 3 cm, respectively.
Figure 3. The effect of fin pitch on the outlet water temperature of the heat exchanger at an air velocity of 3.4 m/s. From Figure 3, it is found that the heat exchanger with a fin pitch of 3 cm yields the best performance amongst others. This section presents the performance of the heat exchanger with a fin pitch of 3 cm, imposing three different ambient air velocity (See Fig. 4). It is found, at an air velocity of 2.4 m/s, the average water temperature at the heat exchanger outlet decreases by 4.5%. When the air velocity is increased to 2.8 and 3.4 m/s, it is obtained that the average outlet water temperature decrease by 4.8% and 5%, respectively.

Figure 4. The effect of air velocity on the outlet water temperature of the heat exchanger with a fin pitch of 3 cm.

3.2. Heat transfer rate

The heat transfer rate of the heat exchanger under various configurations is illustrated in Fig. 5. The results reveal that the lowest heat transfer rate is yielded by the finless heat exchanger. The heat transfer rate significantly increases when the fin is mounted on the outer surface of the heat exchanger’s tube. This tendency is understandable as increasing the heat transfer area contributes to increasing the heat transfer rate. It is found that the highest heat transfer rate is generated by the heat
exchanger with a fin pitch of 3 cm, namely at an average value of 5952.6 W. While, for those with the fin pitches of 5 cm and 7 cm are 5.5 % and 10.6 % lower, respectively. When the air velocity is increased to 2.8 m/s and 3.4 m/s (see Fig. 5a and 5b), it is observed that the same tendency occurs (as that with an air velocity of 2.4 m/s), except for the heat transfer rate which increased with increasing the ambient air velocity on the outer surface of the heat exchanger. This phenomenon occurs due to the air velocity is directly proportional to the coefficient of the convective heat transfer of the ambient air in contact with the outer surface of the heat exchanger. The results reveal that increasing the ambient air velocity on the outer surface of the heat exchanger, from 2.8 m/s to 3.4 m/s has increased the heat transfer rate of the heat exchanger for 7.5 %, 5.5 %, 5.4%, and 6.1%.

![Graphs showing heat transfer rate vs. time for different fin pitches and air velocities.](image)

**Figure 5.** The effect of fin pitch on heat transfer rate of the heat exchanger at an air velocity of (a) 2.4 m/s, (b) 2.8 m/s, (c) 3.4 m/s.

Figure 6 shows the heat transfer rate for the heat exchanger with a fin pitch of 3 cm at three different air velocity namely 2.4 m/s, 2.8 m/s, and 3.4 m/s. It is observed that the heat transfer rate of the heat exchanger is directly proportional to the air velocity. This is because the air velocity affects the Reynolds number. The higher the air velocity, the higher the Reynold number is. This higher Reynold number tends to affect the flow pattern of the ambient air pass through the heat exchanger (i.e turbulence flow). As a result, it is influenced by the heat transfer rate of the heat exchanger. It is found that the average heat transfer rate of the heat exchanger is 5952.6 W at an air velocity of 2.4 m/s. The
heat transfer rate increases at an average of 5.2% and 5.6% when the air velocity rises to 2.8 m/s and 3.4 m/s.

3.3. Convective heat transfer coefficient
Figure 7 shows the average convective heat transfer coefficients of ambient air in contact with the outer surface of the heat exchanger for studied configurations. The convective heat transfer coefficient is influenced by air velocity, surface area, and temperature difference. The higher the air velocity, the higher the convection coefficient is attained. This is because the air velocity affects the Reynolds numbers. The higher the air velocity, the higher the Reynolds number is generated. At a relatively higher Reynolds number, the fluid flow crossing through the heat exchanger (ambient air) tends to become turbulence. The turbulent flow is one of the factors that influence the convection coefficient. It is found that the highest convective heat transfer coefficient occurs on the heat exchanger with a fin pitch of 3 cm namely 211,75 W/m²·K, 223,81 W/m²·K, and 235,85 W/m²·K, at an ambient air velocity of 2.4 m/s, 2.8 m/s and 3.4 m/s.

4. Summary
The performance of the heat exchanger could be improved by adding fins on its outer surface. The results reveal that the addition of fins to the outer surface of the heat exchanger can significantly increase the heat transfer rate and the convection heat transfer coefficient. The highest heat transfer
rate and the convective heat transfer coefficient are yielded by the heat exchanger with a fin pitch of 3 cm. These tendencies are affected by the area of the heat transfer and the turbulent flow regime of the air cross through the heat exchanger.

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