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U-Value Analysis of Coil in Box Heat Exchangers Using Log Mean Temperature Difference (LMTD) Method

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Abstract

Heat exchangers take an important role in the vapor compression refrigeration system as either condenser or evaporator. The aim of this study is to develop a coil in box heat exchanger and analyze its performance in the term of overall heat transfer coefficient (U-Value). The device consisted of an insulated box with dimensions of 28 cm x 18 cm x 20 cm and the copper pipe with 0.006 m diameter and 3.65 m length. The heat was exchanged between the refrigerant R134a inside the pipe and the air outside the copper pipe. The temperatures at the inlets and outlets were measured by K-type thermocouples. Multiple experiments with the different air velocities were conducted. The log mean temperature difference (LMTD) method was used to analyze the overall heat transfer coefficient (U-Value) of the heat exchanger. The results show that the average U-Value was 76.9 W/(m2K).
***Keywords**: heat exchangers, evaporator, refrigeration, vapor compression, coil in box*

1. Introduction

A heat exchanger is one of the important devices in the process industry [1]. Usually heat exchanger is not only studied by theory, but also in the practice [2]. Several types of the common heat exchangers are shell and tube [3], [4], plate and frame [5], [6], and helical coil. The heat exchanger is used to exchange the heat between the two mediums. The development of heat exchanger technology aimed to enhance the heat transfer rate [7]. Heat exchanger is sometimes not only used to change the temperature but also to change the phase, such as condenser or evaporator.

An evaporator is one of the main components in the vapor compression refrigeration (VCR) system. The refrigerant experiences phase change from liquid (or mixture) into vapor in this component. On the other hand, air is the most common medium that is used for exchange the heat in the evaporator. The air is flown to the evaporator thus the heat from the air is absorbed by the refrigerant for evaporation process.

The simplest configuration of heat exchanger is coil pipe geometry. Many studies have been conducted to investigate its applications and performance. Zainudin et al. applied the helical coil heat exchanger to utilize the waste heat from Diesel engine [8]. Their designed heat exchanger can achieve the effectiveness of 67.8% but it decreased dramatically as the increase of air mass flowrate. Hasan et al. studied the use of nanofluids in the helical coil heat exchanger [9]. They used water based nanofluids: Al2O3, CuO, SiO2, and ZnO with 4% nanofluid concentration. The results showed that those nanofluid can increase the heat transfer rate 17 % to 80 % which depends on the geometry. Zhang and Liu studied the helical coil heat exchanger using computational fluid dynamics (CFD) analysis [10]. They reported that the pressure drop and outlet temperature was approximately linear increased by the number of coil turns. Andrzejczyk and Muszyński investigated the modification of external coil surface on the heat exchanger effectiveness [11]. It was observed that the U-value of the heat

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exchanger increased at the larger Dean number on the inner coil tube. Titus et al., compared the helical coil heat exchangers with and without core [12]. They use CFD method for the analysis and the result showed that the heat transfer rate on the coil with core is higher than without core. Saleh et al, studied the use of helical coil heat exchanger to heating the heavy fuel oil [13]. They concluded that the flow in the helical coil tube was affected by centrifugal forces. Salman et al., made an innovation on the helical tape in the double pipe heat exchanger [14]. They reported that the higher pressure drop was obtained when using minimum pitch and higher Reynolds number.

In this study, the coil pipe in box heat exchanger was developed and its performances were analyzed. This device was used as an evaporator in the vapor compression refrigeration cycle. The overall heat transfer coefficient (U-value) was chosen as the main parameter since it considers the ability of the device to exchange the heat. The log mean temperature difference (LMTD) method was used to estimate the U-value.

2. Methods

Figure 1 shows the schematic of the coil in box heat exchanges. The developed heat exchanger consisted of an insulated box with the outer dimensions of 28 cm x 18 cm x 20 cm. Copper coil pipe was placed inside the box with the dimension of 0.6 cm diameter and 3.54 m length. On the top of the box, the fan was installed as the air mover and the PVC pipe with diameter of 6 cm acted as the outing channel of the air. The heat exchanger was used as the evaporator in the vapor compression refrigeration cycle. Therefore, the refrigerant R134a flowed through the copper pipe while the air flowed through inside the box, thus the heat was exchanged between them.

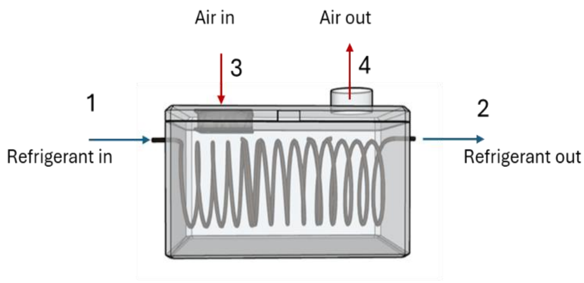

Figure 1. Schematic of coil in box heat exchangers

The temperatures at point 1 to point 4 and the velocities of the air were measured by using K-type thermocouples and anemometer, respectively. The air velocities varied from 1.3 m/s to 3.1 m/s.

Once all the data had been obtained, the overall heat transfer coefficient (U-Value) of the heat exchanger was evaluated as the main parameter to show its performance. The log mean temperature difference (LMTD) method was used. To get the U-Value, the air mass flow rate ($\dot{m}_{air}$) was calculated by using equation (1).

$$\dot{m}_{air} = \rho_{air} A_{PVC} v_{air} \quad (1)$$

Where ρ_{air} is the air density, A_{PVC} is the cross-sectional area of the PVC pipe, and v_{air} is the velocity of the air.

The amount of heat exchange between the two fluids ($\dot{Q}_{HX}$) was calculated by using equation (2)

$$\dot{Q}_{HX} = \dot{m}_{air} c_{air} (T_3 - T_4) \quad (2)$$

Where c_{air} is the specific heat of the air, T_1 is the temperature at point 1, and T_4 is the temperature at point 3.

Since the heat exchange rate was also heat absorbed by the copper pipe, the U-value can be calculated by using equations (3) and (4).

$$\dot{Q}_{HX} = U A_p \Delta T_{LMTD} \quad (3)$$

$$\Delta T_{LMTD} = \frac{(T_3 - T_1) - (T_4 - T_2)}{ln \frac{(T_3 - T_1)}{(T_4 - T_2)}} \quad (4)$$

3. Result and Discussion

The effect of air velocities on the temperature difference at the air and the refrigerant is shown in figure 2. The temperature difference of refrigerant was higher than the air although it was relatively more constant. It meant that the heat absorbed by the refrigerant is also relatively constant. The refrigerant in evaporator (heat exchanger) first experienced phase change from mixture to vapor, which is latent heat. It implied the temperature was not changed during evaporation. Then, the temperature increased after the refrigerant became vapor. It resulted in the increasing temperature of the refrigerant. The higher temperature difference on the refrigerant might be caused by the low mass flow rate of the refrigerant. Since the heat absorbed by the refrigerant is constant, it made the temperature difference on the air smaller at higher velocity.

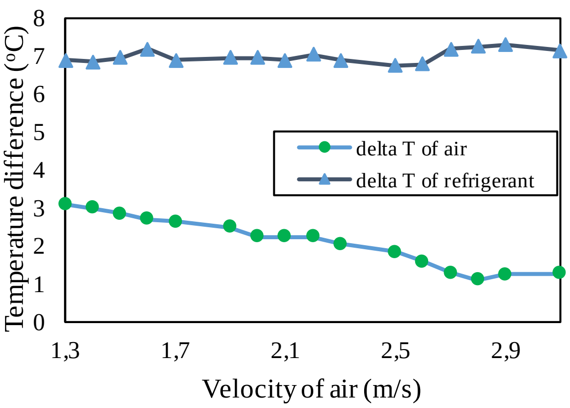

Figure 2. Temperature difference of air and refrigerant

The effect of air velocities on the U-value of the heat exchanger is shown in figure 3. The u-value was relatively not changed by the velocity. The effectiveness of heat exchanger is defined as the ratio between the actual heat transfer rate to the maximum possible heat transfer. The contact duration between the pipe surface and moving air molecule become shorter at higher air mass flow rate. This phenomena led to the low effectiveness heat exchange process. In the empirical method, called NTU-effectiveness method, the heat transfer rate is evaluated by calculating the number transfer unit (NTU). The higher NTU creates higher effectivness of heat exchanger. However, the NTU is inveresly proportional to the mass flow rate. As a result, the higher velocity of air flow caused lower effectiveness of heat exchangers. The effectiveness of heat exchanger and air mass flow rate were cancelled out each other. Based on this experiment results, the average U-value of this heat exchangers is 76.8 W/(m^2K). This value was reasonable as the typical U-value of air-cooled heat exchangers are at 60 to 180 W/m^2K [15].

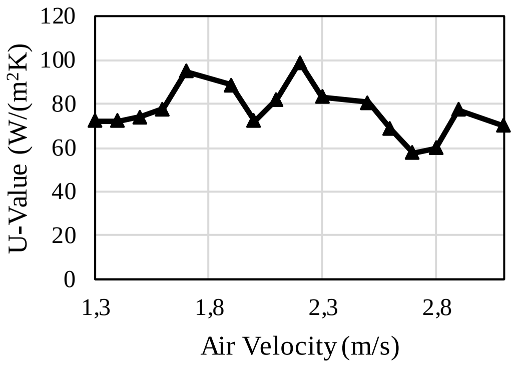

Figure 3. The effect of air velocities on the U-Value

4. Conclusion

This work conducted the experimental evaluation of coil in box heat exchangers. The heat exchanger was used as the evaporator for the small capacity of refrigeration system. The main performance of this investigation was the overall heat transfer coefficient, which is called U-value. Log mean temperature difference was used to estimate the U-value. The results showed that the average U-value was obtained at 76.8 W/(m^2K) with the standard deviation at 11.2 W/(m^2K). This result was reasonable as the typical air-cooled heat exchangers.

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