Design of heat exchanger (evaporator) type of staggered tube cross-flow as modified evaporator AC-split

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Abstract. This study aims to make a tube group type evaporator design alternately with crossing flow as a result of modification of split PK 1 evaporator AC and to evaporate the working fluid, namely R-22, to environmental so that it also simultaneously cools the room. The evaporator designed has a length of 26 cm, a width of 16 cm and a height of 84.2 cm, with a tube diameter of 6.35 mm, a tube length of 58 cm and as many as 25 passes, consisting of 5 rows and 5 columns with alternating positions, distance between tubes 15 mm vertically and horizontally. With this design, the evaporator can absorb heat duty from the room of 813 W.

1. Introduction
The increase of global environmental problems, efficient energy utilization becomes an ever more urgent target in science and technology [1]. Among diverse elementary techniques to be improved, the heat exchanger is one of the major components common in a wide variety of thermal energy handling processes, such as conversion, transport, consumption and storage [2]. Improvement of heat exchanger performance affects both directly and indirectly the performance of various devices and systems, and it would lead to better utility and industrial energy plants, air-conditioning and water heater, manufacturing processes, transportation systems, and even information devices, all of which should contribute to reduction of emission of greenhouse effect gases [3-5]. One of the method for improving performance refrigeration is modification evaporative cooling.

Several studies on the applied heat exchanger (evaporator) on air conditioning systems have been found in the literature. [6] investigated the heat transfer characteristics for staggered tube banks. This paper analyzes the performance for various tube spacing, tube locations and Reynolds numbers. [7] simulated and design tools for air-to-refrigerant heat exchanger for improving effectiveness and efficiency. Simulated used a variety of working fluids and correlation of heat transfer and pressure drop. [8] studied the heat transfer and pressure drop characteristics of tube-fin evaporators. [9] analyses flow and heat transfer characteristic of evaporator using tube shape. It showed the average heat transfer coefficient is approximately 2.2 %, 4.2%, and 11.2 % higher than the circular tube. [10] experiment the gas condensation in a multi-row staggered tube bundle heat exchanger. There is a suitable cooling water flow rate with an adequately low wall temperature and an adequately high transfer coefficient and condensate capture rate. It’s showed that the increase in the cooling water temperature, the condensate capture rate decrease, however, the heat transfer coefficient increases under a similar condition.
The objective of the current work is to design a tube bank of the evaporator with staggered tube cross-flow. The staggered heat exchanger was design based on the cooling capacity needed. It was expected that the staggered heat exchanger would be applied in the air conditioning system.

2. Method
In designing this evaporator, the capability and purpose of the evaporator will be determined first. Evaporator designed to cool the room with a cooling capacity of 1 PK. The cooling fluid or refractive used is R-22 refrigerant. The designed evaporator is a type of tube banks with a crossing flow and without fins. The reason for choosing the tube banks type where the tube banks type can produce lower air temperatures than the types of open pipes which are generally used in Split AC, can reduce the length of the tubes used, as well as easier maintenance. On the other hand, the consequence of using this type is that it will use more reforestation and more complicated manufacturing. The position of the staggered tube is chosen in this design because it has better heat transfer than the parallel tube position. As it is known that the use of fins will be able to help increase the effectiveness of heat transfer in a heat exchanger, but in this study carried out by without using fins due to several considerations such as increased effectiveness with the use of fins for costs that are not suitable, and maintenance which is easily damaged or bent and is not practical compared to not using fins.

The design is viewed from the ideal cycle of vapor compression, the amount of cooling capacity can be obtained, then the assumptions needed to obtain the dimensions of the evaporator are designed such as ambient air temperature, etc. done to obtain the number of tubes to be used and also the dimensions of the evaporator designed will be obtained.

After knowing enthalpy (i) and entropy (s) at each point on the cycle, then looking for the mass flow rate in the tube is sought by connecting the power formula on the compressor equation (1) with enthalpy changes, cos θ which has been determined by the potential difference, and the current strength has also been determined the calculation is as follows:

\[ m_h = \frac{V x l x \cos \theta}{(l-1)k J/kg} \]  

(1)

To find the value of the heat transfer rate or maximum capacity of the evaporator that will be designed calculated by the equation (2)

\[ Q_{e, max} = m \times (i_1 - i_4) \]  

(2)

The efficiency, \( \eta_f \) determined by the equation (3)

\[ \eta_f = \frac{\tanh(mL_c)}{mL_c} \]  

(3)

Where, \( m = \frac{h}{kA} \), and convection coefficient (h), and A is determined the following equation (4)

\[ A = \frac{n dt}{T} \]  

(4)

To calculate the effectiveness of the evaporator, determined by the equation (5)

\[ e = \frac{i_{air, in} - i_{air, out}}{i_{air, in} - i_{air, (T_{ref,in})}} \]  

(5)

The capacity of evaporator tube banks can be obtained as follows (6)

\[ Q_e = \frac{L}{\eta_f} \times Q_{e, max} \]  

(6)

Use the design of the type and dimensions of the model tube heat exchanger tube banks with the settlement of zigzag (staggered) because it is more effective than arranged in parallel. The number of tube rows can be determined by the following equation (7)

\[ Dp > x(n - 0.5) + x + d \]  

(7)

Fluid properties (air) are obtained from the air properties table, and the average temperature difference of logarithms is obtained by equation (8)

\[ \Delta T_{lm} = \frac{(T_{s} - T_{∞})(T_{s} - T_{∞})}{ln ((T_{s} - T_{∞})/(T_{s} - T_{∞}))} \]  

(8)

The air velocity through a heat exchanger is obtained by the fluid flow discharge equation (9)

\[ A_{in}V_{in} = A_{out}V_{out} \]  

(9)

The maximum speed of the transverse determined from equation (10)
\[ S_D = \sqrt{15^2 + \left(\frac{15}{2}\right)^2} \]  
\[ (10) \]

The heat transfer value per unit tube length \((q')\), the heat transfer capacity that is designed and the tube length is adjusted to the length of the blower used, so that it is calculated by the equation (11)

\[ q' = \frac{Q}{h} \]  
\[ (11) \]

3. Results and discussions

Before designing a heat exchanger, the capability of a heat exchanger can be determined in advance. Heat transfer or the maximum capacity of evaporator is 813 W. In designing this evaporator using the ideal cycle of vapor compression. Analysis of the ideal vapor compression cycle, the pressure on the evaporator 60 psi and the pressure on the condenser is 290 psi. So that the enthalpy and entropy can be determined using table thermodynamic refrigerant R22. The model of heat exchanger designed is a tube banks model with an arrangement of tubes in a staggered because they are more effective than arranged in parallel. The dimension of the tube heat exchanger is ¼ ". The kind of propeller used is horizontal blower with height 58 cm, diameter 9 cm and tube spacing is 1.5 cm.

- A number of tube heat exchanger calculated with equation 8:
  \[ Dp > x(n - 0.5) + x + d \]
  \[ 9 > 1.5(n - 0.5) + 1.5 + 0.635 \]
  \[ n < 5.076 \]

- Properties of air
  \( T_w = 30 \, ^\circ C = 303 \, K \)
  \( C_p = 1007.12 \, J/kgK \)
  \( v = 16.1918 \times 10^{-6} \, m^2/s \)
  \( k = 26.522 \times 10^{-3} \, W/mK \)
  \( Pr = 0.70658 \)
  \( \rho = 1.1514 \, kg/m^3 \)
  \( T_s = 4 \, ^\circ C = 277 \, K \)
  \( \rho = 1.1514 \, kg/m^3 \)
  \( Pr = 0.71298 \)
  \( T_f = \frac{4+30}{2} + 273 = 290 \, K \)
  \( v = 15 \times 10^{-6} \, m^2/s \)
  \( k = 25.5 \times 10^{-3} \, W/mK \)
  \( Pr = 0.7096 \)

- The Different mean of temperature with equation (8):
  \[ \Delta T_{lm} = \frac{(4 - 30) - (4 - 24)}{\ln \left(\frac{(4 - 30)/(4 - 24)}{\ln (4 - 30) - (4 - 24)}\right)} \]
  \[ \Delta T_{lm} = 22.868 \]

- The velocity of air in a heat exchanger with equation (9):
  \[ 58 \times 8.5 \times V_{in} = 58 \times 5.5 \times 3 \]
  \[ V_{in} = 1.941 \, m/s \]

- Velocity transversal with equation (10):
  \[ S_D = \sqrt{15^2 + \left(\frac{15}{2}\right)^2} \]
  \[ S_D = 16.77 \]
  \[ \frac{S_T + D}{2} = \frac{15 + 6.35}{2} = 10.675 \]

Because, \( S_D > \frac{S_T+D}{2} \) the maximum of velocity.
\[ V_{\text{max}} = \frac{15}{15 - 6.35}^{1.941} \]
\[ V_{\text{max}} = 3.36 \text{ m/s} \]

- **Reynold number** (Re) can be calculated:
  \[ Re_{D,\text{max}} = \frac{3.36 \times 0.00635}{16.1918 \times 10^{-6}} \]
  \[ Re_{D,\text{max}} = 1317.704 \]

- Heat transfer as long the tube (q’) calculate with equation (11):
  \[ q' = \frac{-813.34}{0.58} \]
  \[ q' = -1402.31 \text{ W/m} \]
  
- Because the number of tubes not specified, so calculate the coefficient of heat transfer:
  \[ q' = N(\bar{h} \times \pi \times D \times \Delta T_{\text{lm}}) \]
  \[ -1402.31 = N \times \bar{h} \times \pi \times 0.00635 \times 22.868 \]
  \[ \bar{h} = \frac{2416.306}{N} \]

- **Nusselt number** with Zukaukas equation:
  \[ \bar{Nu}_D = C_2 \times C_1 \times Re_{D,\text{max}}^m \times Pr^{0.36} \times (\frac{Pr}{Pr_s})^{0.25} \]
  \[ \bar{Nu}_D = C_2 \times 0.35 \times 1317.704^{0.6} \times 0.70658^{0.36} \times (\frac{0.70658}{0.71298})^{0.25} \]
  \[ \bar{Nu}_D = C_2 \times 22.944 \]

- Number of column (N\(_L\))
  \[ \bar{h} = \frac{\bar{Nu}_D \times k}{D} \]
  \[ \frac{2416.306}{N} = C_2 \times 22.944 \times \frac{0.026522}{0.00635} \]
  \[ \frac{2416.306}{N \times 5} = C_2 \times 22.944 \times \frac{0.026522}{0.00635} \]
  \[ N_L \times C_2 = 5.04 \]

- Value of \(N_L \times C_2\) with variation longitudinal of the tube (S\(_L\)):

| No | S\(_L\) (mm) | \(N_L \times C_2\) |
|----|--------------|--------------------|
| 1  | 14           | 4.97               |
| 2  | 15           | 5.04               |
| 3  | 16           | 5.11               |
| 4  | 17           | 5.17               |

From an above, the value of \(N_L \times C_2\) number of Column is 5.
Figure 1. Design of coil evaporator.

Figure 1 is the design of the heat exchanger with the number of columns is 5 and the length of tube 26 cm and the tube spacing is 15 mm.

Figure 2. Design of evaporator.

Figure 2 designing the dimensions of the Evaporator Frame, using an iron profile L with a thickness of 1.4 mm to form a frame of heat exchanger which will be connected by using bolts and nuts. The following is table from the framework.

| No | Dimension | Unit | Quantity |
|----|-----------|------|----------|
| 1  | 840 x 40 x 40 | mm   | 4        |
| 2  | 160 x 40 x 40 | mm   | 4        |
| 3  | 260 x 40 x 40 | mm   | 4        |

4. Conclusions
Tube type heat exchanger type staggered tube cross-flow has been designed and built, the maximum heat capacity of the evaporator 813 W, with R22 refraction. The designed evaporator has a length of 26 cm, a width of 16 cm and a height of 84.2 cm, with a tube bank passageway diameter of 6.35 mm, a tube length of 58 cm and as many as 25 passes, consisting of 5 lines and 5 staggered positions. The distance between the tubes is 15 mm vertically and horizontally.
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