The box-type condenser design used in solar adsorption refrigerator

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Abstract. This study aims to create a fin-type condenser design on a solar adsorption refrigerator with a cross-flow to condense the working fluid, methanol, cooling fluid, and environmental air. The designed condenser has a height of 57 cm, a width of 40 cm. A diameter of horizontal pipe 2.5 cm, a diameter of vertical pipe of 1.9 cm, the distance between pipes 5 cm, fin length of 40 cm, fin width of 7 cm, fin thickness of 0.2 cm, the distance between the fin is 2.05 cm, the number of fins 15 pieces, the number of vertical pipes 5 and 2 horizontal pipes. From the theoretical calculations, the effectiveness of the condenser 0.57.

1. Introduction
Solar energy is a renewable energy that can be used as a source of heat energy and electricity [1]. One of the uses of solar energy with the use of solar heat is a solar cooling engine. The refrigerator advantage is that it has a low regeneration temperature, environmentally friendly, does not require electrical energy, and has no rotating parts. The refrigerator is formed from several main components, one of which is a condenser. The condenser reduces temperature or to condense vapors so that there is a phase change from steam to liquid [2]. Increasing the cooling engine effectiveness can be done by increasing the surface area by adding fins to the condenser. Fins on the condenser function to increase the rate of heat transfer from the condenser's surface to the environment [3]. The advantages of a condenser that are designed are using air as a cooling fluid, its simple shape, easy to manufacture, easy to find materials and a source of energy obtained from solar heat. This design aims to design a fin-type condenser that can increase the rate of heat transfer from the surface area to the environment and know the dimensions of the condenser component and know the theoretical effectiveness of the condenser. Choosing the adsorbent-refrigerant partner must be very careful because to obtain effective results, it is necessary to have an appropriate selection system. There is a combination of adsorbent and adsorbate available, and each has certain advantages and disadvantages. In this study, the adsorbent-refrigerant pair used is activated carbon and methanol. Activated carbon is a porous solid and contains 85-95% carbon, obtained by high heating temperatures in materials containing carbon [4,5]. The activated carbon adsorbent used in this study was made from coconut shells.
2. Methodology

2.1. Working Principles

Adsorption process occurs when a fluid, either liquid or gas, is bound by a solid and finally forms a thin layer on the surface of the solid [6]. The process of adsorption and desorption is an event that occurs reversibly. Adsorption is an exothermic process when solids and fluids release heat, which causes decreased movement of the methanol molecules so that the adsorbate sticks to the surface of the adsorbent and forms a thin layer. The adsorption refrigerator requires heat energy, namely solar radiation energy, used as energy for the ongoing cooling process. Figure 1 shows the adsorption cooling cycle. This adsorption cooling system consists of four methods, which can be explained as follows.

![Figure 1. Clayperon diagram on the adsorption cycle cooling system [7]](image)

The explanation of figure 1 can be described as follows.

- **The process of heating**
  Starting from point A, the heating process, where the adsorbent is in a state with low-temperature TA and low-pressure Pe (evaporator pressure). This heating process occurs during the day, the AB process: Adsorber receives heat, which causes the temperature of the adsorber to rise then followed by an increase in pressure from evaporation pressure to condensation pressure. During this process, no flow of methanol enters or exits the adsorber.

- **Desorption process**
  The process occurs when the heat is given from point B to D so that an increase in temperature is experienced by an adsorber, which results in the steam desorption. Methanol gas in the adsorbent flows into the condenser to be condensed into a liquid.

- **Cooling process**
  The cooling process occurs at night. The picture above takes place from point D to F; by cooling, the adsorber releases heat, which causes the temperature in the adsorber to fall and is followed by a decrease in from condensation pressure to evaporation pressure.

- **The adsorption processes**
  This process occurs from point F to A. The adsorber experiences a decrease in temperature because it continues to release heat and a pressure drop resulting in the generation of adsorption vapor. The absorption of heat by the adsorbate from the water in the area of the evaporator in the amount of latent heat from the evaporation of the previous adsorbate will produce adsorbate in the form of steam.
There is a combination of adsorbent and adsorbate available and each adsorbent and adsorbate has certain advantages and disadvantages. The correct selection depends on the following [10]. The desired characteristics of the cooling system, properties of the adsorbent-adsorbate pair, heat source temperature, affordable cost, availability and impact on the environment.

2.2. Design Scheme
Figure 2 shows the design scheme of the condenser used in the solar adsorption refrigerator.

![Condenser design flow chart](image)
In the design of an air-cooled fin type condenser, first determine the type of fluid flowing in the tube where each hot fluid and cooling fluid has the capacity, temperature, density, and different properties. This condenser is a condenser consisting of cylindrical pipes and square fins with the cross-flow, in terms of construction has a simple shape. The tube used must be able to transfer heat between the fluid in the tube and outside the tube. The tube material used is aluminum because it can transfer high heat, be resistant to corrosion, be resistant to heat, and be resistant to erosion, easily formed affordable prices, and easy to find in the market. The choice of material type and tube size is based on the amount of fluid flow, temperature, corrosive, or not as well as impurities. Tubes that are often used and easily found are ¾ inch and 1-inch tubes. In choosing a tube, another thing to consider is its length. Standard tube lengths are 6 ft (1.83 m), 8 ft (2.44 m), 12 ft (3.66 m) and 16 ft (4.88 m). In designing this condenser, the goals and abilities of the designed condenser are determined first. The designed condenser aims to cool methanol as a hot fluid and air as a cooling fluid. The technical design drawings of the condenser can be seen in figure 3.

![Figure 3. Design engineering drawings](image)

3. Results and Discussions
The condenser is a heat exchanger that serves as the final stage of distillation by converting hot steam to ethanol through the condensate or condensation process. The condenser design calculation is a calculation to find the LMTD value, correction factor, Reynold number, number N, heat transfer convection coefficient, total heat transfer coefficient, heat, surface area, pipe length, pitch number, pitch distance. All equations used are taken from the following literature sources [8,9].
\[ \Delta LM T D = \frac{\Delta T_2 - \Delta T_1}{\ln \left( \frac{\Delta T_2}{\Delta T_1} \right)} \]  

(1)

Where the LMTD is called the log mean temperature difference or the temperature difference at one end of the heat minus the temperature difference at the other end divided by the natural logarithm rather than the comparison of the two temperature differences at the other Nusselt number, an alternative flow configuration is a heat exchanger where the fluid moves in the cross-flow direction or at an angle perpendicular to each other through the heat exchanger. If a heat exchanger that is not a double pipe type is used, heat transfer is calculated by applying correction factors concerning the LMTD for the double-flow pipeline in the opposite direction with the same hot and cold fluid temperatures. To find the conduction heat transfer in units (W) can be calculated with the following equation.

\[ Q_{cond} = k \cdot A \cdot (T_s - T_\infty) \Delta x \]  

(2)

Where \( k \) is the thermal conductivity of the material (W/m·K), \( A \) is the surface area (m\(^2\)), \( T_s, T_\infty \) is the average temperature, and the ambient temperature (K) and \( \Delta x \) is the thickness of the material (m). To find the radiation heat transfer in the collector (W) can be calculated with the following equation.

\[ Q_{rad} = \varepsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_\infty^4) \]  

(3)

Where \( \varepsilon \) is the material emissivity, \( \sigma \) is Stefan-Boltzman's constant (5.63 × 10\(^{-8}\) W/m\(^2\)K\(^4\)), \( A \) is the surface area (m\(^2\)), and \( T_s, T_\infty \) is the average temperature and ambient temperature (K). To find the convection heat transfer in the condenser (Watt) can be calculated with the following equation.

\[ Q_{conv} = h A \cdot (T_s - T_\infty) \]  

(4)

Where \( h \) is the convection heat transfer coefficient (W/m\(^2\)·K), \( A \) is the surface area (m\(^2\)), and \( T_s, T_\infty \) is the average temperature and ambient temperature (K). To find the following equation can calculate the convection heat transfer coefficient.

\[ GrL = (T_s - T_\infty)3\nu^2 \]  

(5)

\[ RaL = GrL \cdot Pr \]  

(6)

\[ Nu = h. \]  

(7)

Where \( g \) is the acceleration due to gravity (m/s\(^2\)), \( \beta \) is the volume expansion coefficient (1/K), and \( L \) is the characteristic length (m). The notation \( \nu \) is kinematic fluid viscosity (m\(^2\)/s), \( h \) is convection coefficient (W/m\(^2\)K), \( k \) is fluid thermal conductivity (W/m\(^2\)K), \( GrL \) is the Grashof number \( RaL \) is the Rayleigh number, and \( Nu \) is the Nusselt number. To find the sensible heat in the evaporator can be calculated with the following equation.

\[ Q_s = m \cdot C_p \cdot \Delta T \]  

(8)

Where \( C_p \) is the specific sensible heat capacity (kJ/kg·K), \( \Delta T \) is the change in temperature (K), and \( m \) is the mass of the body (kg). To find the latent heat in the evaporator can be calculated with the following equation.

\[ \varepsilon = \frac{Q}{Q_{max}} \]  

(9)
Where $Q$ is the actual heat transfer rate, and $Q_{max}$ is the possible heat transfer rate. The actual heat transfer rate of a heat exchanger is determined from the equation of the balance of hot or cold fluid energy, as follows:

$$Q = C_c(T_c, \text{out} - T_c, \text{in}) = C_h(T_h, \text{in} - T_h, \text{out})$$  \hspace{1cm} (10)

With $C_c = m_c C_{pc}$ is the rate of heat capacity of the cold fluid and $C_h = m_h C_{ph}$ is the rate of heat capacity of the hot fluid. So the maximum heat transfer rate that might occur in a heat exchanger is:

$$Q_{max} = C_{min}(T_h, \text{in} - T_c, \text{in})$$  \hspace{1cm} (11)

The calculation in the condenser design and the results can be seen in the table 1.

| Calculation                        | Results     |
|------------------------------------|-------------|
| Log Mean Temperature Differential (LMTD) | 231.69 K   |
| Overall heat transfer (U)          | 15.52 W/m²K|
| Total cross-sectional area         | 0.171 m²    |
| The total length of pipe 3/4 "(L) | 1.84 m      |
| Length of each track               | 0.36 m      |

Based on the design calculation process, a condenser design research has been produced with the following specifications:

- Material : Aluminum
- Condenser width : 400 mm
- Number of pipes 3/4 inch : 5 pieces
- Number of pipes 1 inch : 2 pieces
- Outside diameter of pipe : 3/4 inch (19 mm) and 1 inch (25 mm)
- The inner diameter of the pipe: 3/4 inch (15 mm) and 1 inch (21 mm)
- Number of condenser fins : 15 pieces
- Dimension of condenser fins : 400 mm × 70 mm × 2 mm
- Distance between pipes (ST) : 50 mm

A shape of condenser that has been designed using AutoCAD is shown figure 4.
4. Conclusions
A condenser has been designed as a component of a solar adsorption refrigerator. The condenser is made of aluminum. The condenser main dimensions are 400 mm wide, 19 mm and 25 mm outside diameter, 15 mm, and 21 mm inside diameter. The fins number of the condenser is 15 pieces. Based on theoretical calculations, the effectiveness of the condenser designed is 0.57.

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