Design of the box type evaporator in the solar adsorption refrigerator

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Abstract. The evaporator is a device used to separate two phases between liquid-gas and liquid-liquid by using heating media. The model uses aluminum material with dimensions 170 mm x 170 mm x 240 mm and uses 3 mm aluminum thickness and three pieces of aluminum pipe with dimensions of 100 mm. The choice of material used aims to obtain optimal results from the work of the evaporator. The effect of temperature is significant in the process that occurs in the evaporator will determine the effectiveness of the evaporator so that it can separate the water content in methanol. By heating, until one component evaporates on its boiling route, it can separate it from other parts by using methanol with 90% purity. The results of the design that is made produce an evaporator with a volume of 5 liters. The minimum evaporator temperature obtained during testing occurs in the second cycle of 0.5°C. Several factors affect the performance of an evaporator. The total heat needed in the process of reducing the maximum water temperature to the minimum water temperature and the latent heat required by methanol to evaporate.

1. Introduction

The need for cooling systems in remote areas for various needs in the preservation and storage of food is felt to be increasing. While existing conventional cooling systems may not be used because not all remote areas have electricity networks, so a simple solar cooling system is one alternative for solving problems of cooling system needs in remote areas. One of the cooling system alternatives is the solar adsorption refrigerator. A solar adsorption refrigerator consists of the three main components, namely collector, condenser, and evaporator [1]. The research aims to design and determine the performance of box type evaporator in solar adsorption refrigerator.

The adsorption cycle includes a cycle of thermodynamics that can produce a refrigeration effect, as shown in figure 1. This cycle utilizes the ability to bind and release a chemical between the refrigerant and absorbent. In the adsorption system, the adsorbed phase in solid is called adsorbate, while the solid is adsorbent. The adsorption process can occur due to the attraction atom or molecule on the surface of an unbalanced solid and the existence of this force, a solid that can attract other particles that come in contact with the solid's both the gas phase and the solution into its surface [2].
Figure 1. The ideal clapeyron adsorption cycle diagram [3]

The process that occurs can be described, as shown in figure 1. The heating process starts from point A where the adsorbent is at low-temperature $T_A$ and low-pressure $P_e$ or evaporator pressure. In this process, the adsorbate is still in the form of adsorption vapor (Heating Process). The desorption process occurs when the heat is given from point B to C so that the adsorber experiences an increase in temperature, which causes the desorption of steam. The adsorbate in the adsorbent in the gas form flows into the condenser to undergo the condensation process to become liquid and flow to the condenser (Desorption Process). The cooling process takes place from point C to D. The adsorber releases heat by cooling so that a decrease follows the temperature in the adsorber drops and pressure from condensation pressure to evaporation pressure (Cooling Process). The adsorption process takes place from point D to A. The adsorber continues to release heat so that the adsorber experiences a decrease in temperature and pressure, which causes adsorption vapor. The adsorbate in the steam form is produced from the absorption of heat by the adsorbate from the water around the evaporator as much as the latent heat of the adsorbate evaporation (Adsorption Process).

Adsorbents are solid substances that can absorb fluid particles in an adsorption process. Adsorbents are specific and are made from porous materials [4,5]. Several types of adsorbents are effectively used, including zeolites, silica gel, and activated carbon. The adsorbent choice in the adsorption process must be adjusted to nature and condition the substance to be adsorbed. In this test, the type of adsorbent used is activated carbon. Activated carbon is a material in the form of carbon arm of which consists mostly of free carbon. It has an internal surface to have an excellent absorption ability. Activated carbon generally contains carbon compounds up to 85% to 95%. Methanol is the purest form of alcohol. In the atmosphere of methanol in the form of a liquid that is lightweight, volatile, colorless, flammable, and toxic with a characteristic odor. Methanol is used as an antifreeze coolant, solvent, fuel and as an additive for industrial ethanol [6,7]. Methanol is produced naturally by anaerobic metabolism by bacteria. The result of this process is methanol vapor (in small amounts) in the air. After a few days, the methanol vapor will be oxidized by oxygen with sunlight's help into carbon dioxide and water.
2. Methodology
The evaporator component on the solar adsorption refrigerator also functions as a refrigerating container. The container of refined methanol is made on cooled water and separated by a stainless steel plate. The heat transfer process that occurs in the evaporator can be described as follows [8, 9].

The sensible heat absorbed by the evaporator plate is

\[ Q_{ev} = m_{ev} \times C_{pe} \times \Delta T \]  

(1)

Where \( m_{ev} \) is evaporator mass (kg), \( C_{pe} \) is the specific heat of the evaporator plate (kJ/kg·°C), and \( \Delta T \) is the difference between the maximum and the minimum plate temperature (°C). The cooled media in this research is water, so the calculated heat is the sensible heat from the water. The sensible heat needed to reduce the water temperature from the maximum temperature to the minimum temperature is

\[ Q_{water} = V_{water} \times \rho_{water} \times C_{p-water} \times (T_{water-max} - T_{water-min}) \]  

(2)

The sensible heat absorbed by the methanol refrigerant from the evaporator wall is:

\[ Q_{s-m} = V_{m} \times \rho_{m} \times C_{pm} \times (T_{p-max} - T_{p-min}) \]  

(3)

The latent heat needed by methanol to evaporate is

\[ Q_{L-m} = V_{m-L} \times \rho_{m} \times h_{fm} \]  

(4)

where \( V_{m-L} \) is the volume of methanol that has evaporated, \( \rho_{m} \) is methanol density (kg/m³) and \( h_{fm} \) is the latent heat of methanol (1155 kJ/kg).

The total heat needed in the process of reducing the maximum water temperature to the minimum water temperature is:

\[ Q_{total} = Q_{ev} + Q_{water} + Q_{s-m} \]  

(5)

Evaporator effectiveness value is the ratio between total energy to reduce water temperature from maximum temperature to minimum temperature with the amount of latent heat absorbed by methanol during the evaporation process: [10, 11]

\[ \eta_{eva} = Q_{total} / Q_{L-m} \]  

(6)

3. Results and Discussions

3.1. Evaporator design
For the evaporator material used, namely aluminum composite panel (ACP), wood, Styrofoam, aluminum Foil is the material used as an evaporator body. The aluminum is a non-ferrous metal that has mild and corrosion-resistant properties. Aluminum is used as an alloy of various pure metals because it does not lose its lightness and mechanical properties. Its ability to cast is improved by adding other elements. The alloying elements are copper, silicon, magnesium, manganese, nickel, which can change the properties of aluminum alloys. The refrigeration system's evaporator is a very important heat exchanger in the refrigeration cycle that is to cool and release heat from fluids such as air, water, or some other object. In the evaporator, liquid methanol evaporates when the adsorbent temperature rises during the adsorbent heating. Methanol will melt in the condenser, and the liquid will accumulate again in the evaporator, and at night the adsorbent temperature will drop slowly and absorb methanol. In this study, the evaporator area design is done to obtain the length and width of the evaporator as a container for the refrigeration process.

The manufacturing stage of the evaporator can be described briefly as follows. Prepare an aluminum plate with a thickness of 3 mm and an aluminum pipe with a diameter of ¾ inch. Cut the plate and pipe according to the shape and dimensions that have been determined. Connect the plates and pipes that have been cut by welding also connect the container for water. Test the evaporator with
a vacuum pump to find out if there are any leaks. If there is no leak, then the evaporator is ready for use.

![Figure 2. Evaporator](image)

The stage in making an evaporator insulation box as follows. Prepare plywood, Styrofoam, black foam, kft foam, Rockwool, and aluminum foil. The shape box using plywood. Insert material into the insulation by the size of which has been planned. Wrap the insulation material with aluminum foil. The shapes and dimensions of the evaporator insulation box used in this study are shown in Figures 3 and 4.

![Figure 3. a) Evaporator insulation box](image) ![Figure 3. b) Interior of the evaporator insulation box](image)

![Figure 4. Upper evaporator insulation box](image)

Top evaporator insulation box specifications as follows.

- Outer dimensions: 326 mm × 326 mm × 296 mm
- Styrofoam thickness: 30 mm
- Thick foam thickness: 20 mm
• Triplex thickness: 8 mm

3.2. Evaporator testing
Evaporators that have been successfully made are then tested. The test is carried out together with other components in the solar adsorption refrigeration unit. The testing process is carried out for three cycles, where each period lasts 24 hours. Figures 5, 6, and 7 show the evaporator temperature distribution and water-cooled for 24 hours in three cycles. The difference between the evaporator temperature and the temperature of the cooled water is quite small. During the test, a minimum evaporator temperature and cooled water were obtained at 05.00-06.00 WIB. The minimum evaporator temperature obtained during testing occurs in the second cycle of 0.5°C. Several factors affect the performance of an evaporator are the total heat needed in the process of reducing the maximum water temperature to the minimum water temperature and the latent heat needed by methanol to evaporate.

![Figure 5. Temperature distribution of evaporator and water-cooled on the first cycle](Image)
Figure 6. Temperature distribution of evaporator and water-cooled on the second cycle

Figure 7. Temperature distribution of evaporator and water-cooled on the third cycle

4. Conclusions
An evaporator has been designed as a component of a solar adsorption refrigerator. The evaporator has area 0.153 m² and volume 5 liters. The evaporator design using aluminum material with a modulus of elasticity 10. The evaporator designed has evaporator effectiveness of 29%. Consideration for future
research is to add fins on the inside of the evaporator to increase the evaporator effectiveness. And it is assumed that 1 liter of methanol evaporates. To convert 1 liter of methanol, it takes energy (QL) of = 922.72 J and latent heat for methanol L is 1168 kJ / kg.

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