Experimental study of solar adsorption refrigerator using a parabolic collector

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Abstract. Several alternative energy sources have been developed; one of them is solar energy to overcome the future energy crisis. Solar energy can be used as a source of heat energy, used very much, one of which is on the adsorption cycle refrigerator. The adsorption cycle refrigerator tested has three main components, namely the parabolic collector, condenser, and evaporator. In this research, the three main components are made of aluminum because they have a high thermal conductivity value and are resistant to corrosion due to water or refrigerant used. The pairs of adsorbent and refrigerant used were active powder carbon of 10 kg and methanol of 3 liters. The research purpose is to determine the maximum temperature at the collector, the minimum temperature in the cooled water, collector efficiency, and the COP value of the system. The experiment procedure is by heating the solar collector from 08.00 AM-05.00 PM (GMT+7), while the natural cooling process takes place from 05.00 PM-08.00 AM (GMT+7). The results obtained that the maximum temperature of the collector is 126.56°C. The minimum temperature of the water is -0.09°C, the maximum parabolic collector efficiency is 53.39%, and the maximum COP value is 0.000956.

1. Introduction

Today, science and technology are overgrowing, which is balanced with a growing population. Thus the need for energy is getting bigger, which means that the human ability to create energy is increasingly needed. Considering that the most significant energy producer today is still derived from fossil energy, this energy will frequently run out so humans cannot forever depend on this energy. Data of the 2015-2050 National Energy General Plan and The International Energy Outlook 2006 express that Indonesia's fossil vitality potential, including oil, natural gas, and coal, can just keep going for a very long time, 31 years, and 80 years if not found new fossil vitality holds [1]. These increasingly high energy needs, humans must continue to innovate to create energy to meet their energy needs. As is well known, solar energy can be used as a source of heat energy and as a source of electrical energy. One of the applications of the use of solar thermal energy is solar refrigerator. This machine is powered by solar power and uses no electrical energy or mechanical energy at all. With Indonesia's climatic climate, cooling is needed which is generally used for air conditioning. The main advantage of this machine is that the regeneration temperature is relatively low so it is suitable for solar energy applications and does not have rotating parts because all fluid movements take advantage of natural effects so that it does not require electrical energy. Adsorption cycle cooling machine is a gadget used to cool things, for example, natural products, making ice shapes, immunizations and help by using daylight to run the cycle.
2. Methodology

2.1. General Theory of Adsorption

Adsorption is the process by which molecules move and adhere to the surface of a solid. Adsorption is a physical phenomenon that occurs when gas or liquid molecules are contacted with several solid surfaces, and some of these molecules condense on the surface of the solid. Porous solids that suck (adsorption) and release (desorption) a fluid that is inhaled but not accumulated to the surface of the adsorbent is called adsorption. In contrast, what is collected/attached is called an adsorbate. The adsorption cycle that occurs from a solar cooling system is discussed in Figure 1.

![Figure 1. Basic cycle of adsorption improvement [2]](image)

Figure 1 shows the initial conditions of the system at low temperatures and temperatures. The adsorbent has a high concentration of refrigerant and other vessels, including gas in the form of refrigerant. The available adsorbent vessel is heated, which rises in temperature, and the system increases in the adsorbate content in the adsorbent, in this case, is called desorption. The degraded refrigerant is then condensed as a liquid in the second flask by releasing heat into the environment while the pressure and temperature system are still high. When determining an adsorbent-refrigerant pair, many things must be approved to get the optimal and maximum results from the system needed. There is a combination of adsorbent and adsorbate that is suitable, and each has certain advantages and disadvantages in its use. Based on the selection of the appropriate adsorbent-refrigerant pair depends on the desired characteristics of the cooling system, the properties of the adsorbent-adsorbate repair, the temperature of the heat source, cost, fly, and environmental. One type of energy that can be received or released by an object that can be obtained or released is heat. Then this heat energy can be moved or transferred from one object to another.

2.2. The components of the solar adsorption refrigerator

The solar oriented adsorption fridge comprises of a few primary segments, specifically the gatherer, condenser, and evaporator [3]. A brief description of each component can be described as follows. The solar collector can be translated as a heat-transmitted system that generates heat energy by utilizing solar radiation as the primary energy source. It has obtained three types of solar collectors that are questioned in the solar thermal collector system. It also has a solar collector classification based on the dimensions and geometry of the receiver it has, namely, flat plate collector, concentration collector, and evacuated tube collector. A condenser is a tool for making condensation of gas cooling material from compressors with high temperature and high pressure. The condenser is a pipeline that functions as condensation. According to the substance that cools it, the condenser can be three, namely air-cooled condenser, water-cooled condensers, and mixed air and water-cooled condenser (evaporative...
condenser). The evaporator in the refrigeration system is a heat exchanger that plays an essential role in the refrigeration cycle, which is to cool the media. The refrigeration system's purpose is to free heat from fluids such as air, air, or some other object. Based on the coil's shape and surface, the evaporator is divided into three types: bare tube evaporator, plate evaporator, and finned evaporator.

2.3. The intensity of solar radiation
The intensity of solar radiation is the small angle of sunlight coming on the surface of the earth. The amount received is directly proportional to the angle of incidence. To calculate solar radiation received by solar collectors with a slope of 30° so that use the equation [4,5]:

\[ G_{bT} = G_{bn} \cdot \cos \theta T \] (1)

Where \( G_{bn} \) is radiation intensity on the inclined plane (W/m²), and \( G_{bn} \) is the intensity of solar radiation at standard entry angles on horizontal surfaces (W/m²). The \( \cos \theta T \) is an entry angle or angle between the direction of the beam at the normal entrance angle and the direction of the perpendicular component (90°) on the inclined surface.

To calculate the amount of solar radiation for one hour can be determined by the equation:

\[ I_{60 \text{ minute}} = G_{bT} \cdot 3600 \] (2)

Where \( I_{60 \text{ minute}} \) = total intensity of solar radiation for one hour (J/m²) and \( G_{bT} \) is radiation intensity on the inclined plane (W/m²).

2.4. Solar collector
The equation can determine the total radiant heat energy absorbed by a collector surface is [6]

\[ Q_{in} = I_{total} \cdot A \cdot \tau \alpha \] (3)

and

\[ Q_{total \ rad} = I_{total} \cdot A \] (4)

Then the new equation to find the total radiant heat energy absorbed by the surface of the collector is

\[ Q_{in} = Q_{total \ rad} \cdot \tau \alpha \] (5)

Where \( Q_{in} \) is heat energy absorbed by the collector (J), \( I_{total} \) is total solar radiation for one cycle (kJ/m²), and \( Q_{total \ rad} \) is total heat radiation energy received by the collector (J). Notation \( A \) is the surface area of the collector area exposed to sunlight (m²), \( \tau \) is absorptivity of the black plate collector, and \( \alpha \) is absorptivity glass.

The following equation can determine the heat loss at the time of the collector:

\[ Q_{hl,\text{total}} = Q_{hl,\text{top}} + Q_{hl,\text{bottom}} + Q_{hl,\text{side}} \] (6)

Where \( Q_{hl,\text{the total}} \) is heat loss to the collector (J), \( Q_{hl,\text{the top}} \) is heat loss on the upper side of the collector, \( Q_{hl,\text{the bottom}} \) is heat loss at the bottom side of the collector and \( Q_{hl,\text{side}} \) is heat loss on the side of the collector. The radiant heat energy used by the collector is the energy used by the collector or absorbed by the adsorbent (activated carbon) to increase its temperature and then used to release/adsorb the adsorbate (methanol). The equation can calculate the actual thermal energy used by the collector [7]:

\[ Q_b = F'(Q_{in} - Q_{hl,\text{total}}) \] (7)
Where $Q_b$ is radiant heat energy used by the collector, $F'$ is the collector efficiency factor is assumed to be 0.9, $Q_{hl, total}$ is heat loss to the collector (J), and $Q_{in}$ is total heat energy received by the collector (J). The thermal efficiency of the solar collector can be calculated using the equation [8]:

$$\eta = \frac{Q_b}{IA}$$

(8)

Where $\eta$ is the thermal efficiency of solar collectors (%), $Q_b$ is radiant heat energy used by the collector (J), $I$ is the intensity of solar radiation (W/m$^2$), and $A$ is collector surface area (m$^2$).

2.5. Coefficient of Performance
The COP value of the adsorption cycle depends significantly on the condition and efficiency of each component of the collector, condenser, and evaporator system whose prices vary from 0.01 to 0.2. The COP of the refrigerator is calculated using the equation [9,10]:

$$\text{COP} = \frac{Q_{cooling}}{Q_{in}}$$

(9)

Where $Q_{in}$ is heat energy received by the collector (J). The number of cooling effects that can be calculated using the equation:

$$Q_{cooling} = m_{water} C_{water} (T_{water\text{-}max} - T_{water\text{-}min})$$

(10)

Where $Q_{cooling}$ is cooling effect capacity (J), $m_{water}$ is mass of water (kg), $C_{water}$ is the specific heat of hot water (J/kg°C), $T_{water\text{-}max}$ is maximum air temperature (°C), and $T_{water\text{-}min}$ is minimum air temperature (°C)

3. Results and Discussions
The results of tests carried out discuss the conditions of ambient temperature and radiation intensity, changes in temperature of the engine coolant components, and performance coefficients.

3.1. The intensity of solar radiation
Solar radiation began to be monitored on the pyranometer measuring instrument ranged between 06.00 AM to 06.25 AM (GMT+7) and began not monitored again between 06:00 PM and 06:30 PM (GMT+7) during the test. The maximum radiation intensity on these measurements occurs at 12.05 PM-01.35 PM (GMT+7), and the maximum air temperature occurs at 12.15 PM-02.25 PM (GMT+7). For this measurement, the maximum radiation intensity that occurs generally occurs at 10.05 AM-12.10 PM (GMT+7), and the maximum air temperature occurs at 11.20 AM WIB-02.40 PM (GMT+7). Figure 2 displays the characteristics of solar radiation during testing.
3.2. The components temperature

The testing of the performance of the solar adsorption cooling engine has been carried out for three cycles. Data from measurements of changes in temperature of each component of the solar adsorption refrigeration engine can be shown by figures 3, 4, and 5. It can be said that the temperature distribution in each part has fluctuations. The most influential element on a solar adsorption cycle cooling engine is a collector or often also called an adsorber. The collector used in the research is a type of satellite dish. It appears that in the 24-hour testing process, there was a temperature fluctuation on the collector's surface. The maximum collector temperature generally occurs between 12.00 PM-02.00 PM (GMT+7). This condition is certainly also influenced by the amount of solar radiation received at the collector's surface at any time. Fluctuations in the collector's temperature also affect the temperature changes in other components, namely the condenser and temperature. The maximum temperature the collector can achieve during testing is 126.56°C. While the minimum temperature of water to be cooled is obtained by -0.9°C. This condition proves that the process of desorption and adsorption occurs in the solar adsorption cooling engine tested underway naturally.
3.3. The Performance of the Solar Adsorption Refrigerator

The parabolic collector efficiency value obtained during the testing process of several cycles ranges from 49.51 to 53.39%. The main factors affecting the performance of solar collectors are radiation intensity and surface area of the collector. To determine the performance of a solar adsorption refrigerator, it can be seen from the COP values obtained. The amount of COP during testing can be seen in Table 1. The amount of COP obtained from the test results for five cycles is around 0.000636-0.000959. It appears that the COP value obtained varies and is influenced by several factors, including weather conditions, the performance of cooling engine components, especially collectors, and the ability of adsorbents to absorb refrigerants.

Table 1. The COP value obtained

| Experiment | $Q_{\text{cooling}}$ (J) | $Q_{\text{rad}}$ (J) | COP    |
|------------|--------------------------|----------------------|--------|
| Cycle 1    | 2616                     | 4114155              | 0.000636 |
| Cycle 2    | 3505                     | 4661086              | 0.000752 |
| Cycle 3    | 3414                     | 3558751              | 0.000959 |
4. Conclusions
The experiments of solar adsorption refrigerator using a parabolic collector have been carried out. The total radiation intensity received by the collector during the collector heating process on preheating is 4.346 MJ. The first desorption is 4.114 MJ, the second desorption is 4.661 MJ, and the third desorption is 3.558 MJ. The maximum temperature of the solar collector in the preheating process is 126.56°C, the first desorption is 97.79°C, the second desorption is 114.23°C, and the third desorption is 93.12°C. The maximum temperature was obtained during the preheating process at 126.56°C, and the minimum at the third desorption was 93.12°C. The maximum coefficient of performance obtained is 0.00959 during experiments.

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