Photovoltaic driven adsorption-cooling cycle

I Gusti Agung Bagus Wirajati¹, I Nengah Ardita¹ and I Gede Nyoman Suta Waisnawa¹

Mechanical Engineering Department, Bali State Polytechnic, Badung, Bali, Indonesia
igabwirajati@pnb.ac.id, inengahardita@pnb.ac.id, nyomansutawaisnawa@pnb.ac.id

Abstract. In this paper, an adsorption cooling system with drive heat sources from solar power through a photovoltaic system will be introduced. The PV system is used to heat the water collected in the storage tank for further use as the main driving force in the adsorption cooling system. The PV system has been tested and produced a voltage of 21 V with a current of 5.7 A. Whereas the research for the adsorption cooling system, it is only at the simulation test stage to determine the minimum heat source temperature that can be used in operation, which is 60 °C. By this research, it can be ascertained that the PV system is very possible to be applied to the adsorption cooling system so that the combination of the application of a technology system that is very environmentally friendly can be realized.

1. Introduction

Combination technology application among solar power and adsorption cooling systems are considered not only as an alternative to reduce the use of CFCs and HCFCs but also as an energy efficient [1].

The adsorption refrigeration performances without concerning in cycle optimization has been investigated by Sakoda et.al [2], Alam et al. [3], and Khan et al. [4].

Heat source below 100 °C is considered for driving heat in order to gain the effective cooling production. Therefore, an adsorption cycle which is using silica gel and water is chosen because silica gel has the low regeneration temperature compare than that of activated carbon and the latent heat of vaporization of the water has large. For example, zeolite/water et.al. [5] and silica gel/water [6 and 7].

In this paper, a photovoltaic system designed and implemented in order to produce hot water 60 °C as a driven heat source temperature in the adsorption refrigeration proposed cycle. A simulation program using MATLAB is developed to shown the minimum temperature heat source in the proposed adsorption cycle.

The research investigation shown the PV system produced a voltage of 21 V with a current of 5.7 A for 1 array. Meanwhile, based on the simulation for the adsorption system, the minimum heat source temperature that can be used in operation is 60 °C.

2. Photovoltaic Driven Adsorption Working Principle

Figure 1 represent the photovoltaic driven adsorption refrigeration system. Driven heat source temperature in adsorption system came from hot water in the thermal storage tank, which is heated from photovoltaic system.

Since the hot water and cooled water flowed to the hex1 and hex2 then both the temperature and pressure in hex1 will rise up to the condenser pressure and the temperature and pressure in hex2 will go down to the evaporator pressure, respectively. At this time hex1 will be connected to the condenser
and doing the desorption process while hex2 will be connected to the evaporator and doing the adsorption process as well.

![Photovoltaic driven adsorption refrigeration system](image)

**Figure 1.** Photovoltaic driven adsorption refrigeration system scheme.

When the pressure of hex1 and hex2 approaching equal to the pressure in condenser and evaporator, then all valve are closed. At this time the process of pre-heating and pre-cooling occurs where there is no refrigerant flow in the system.

If the pressure of hex1 and hex2 approaches the same as the pressure in the condenser and evaporator, then valve 1 and valve 2 will open so that hex 1 returns to be connected to the condenser and hex 2 connected to the evaporator. The processes of desorption and adsorption occurs again.

During the adsorption process, the evaporator will evaporate water / refrigerant at the evaporator temperature and heat seized from cold water occurs isobarically so that the evaporation process results and produced cooling effect. Evaporation heat is supplied by flowing cold water at low heat source temperatures.

Table 1 and Table 2 constitute the baseline parameter and standard operating conditions adapted in simulation, respectively.

2.1. **Equation in Adsorption Simulation**

2.1.1. **Heat transfer equation**

Heat transfer in evaporator (e), condenser (c) and heat exchanger (h) describes as follow:

\[
T_{e,c,h} = T_{e,c,h} + \left( T_i - T_{e,c,h} \right) \exp \left( \frac{U_{e,c,h} A_{e,c,h}}{m_w C_w} \right)
\]  

(1)

T in the formula 1 denotes the temperature of the liquid and assumed to be uniform in hex, evaporator and condenser. U and A in the formula 1 state the heat transfer parameters, namely the overall heat transfer coefficient and heat transfer area.

2.1.2. **Energy balanced equation**

Energy balance in heat exchanger, evaporator and condenser express below:

\[
(W_s C_s + W_c C_w q + W_h C_h) \frac{dT}{dt} = W_s Q_s \frac{da}{dt} - W_s C_s \delta \left[ y(T-T_c) + (1-y) (T-T_w) \right] \frac{da}{dt} + m_w C_w \varepsilon_a (T_i - T)
\]  

(2)
\[
\begin{align*}
(W_{e,w}+W_{e,h},C_{e,h})\frac{dT_e}{dt} &= m_{e}C_{e}\varepsilon_e(T_{eh,i}-T_{eh,o}) - W_s\left(\frac{d\theta_{ad}}{dt} + \frac{d\theta_{de}}{dt}\right)(L+C_v(T_c-T_e)) \\
(W_{c,w}+W_{c,h},C_{c,h})\frac{dT_c}{dt} &= \dot{m}_{cw}C_{cw}\varepsilon_c(T_{cw,i}-T_{cw,o}) - W_s\left(\frac{d\theta_{de}}{dt} + \frac{d\theta_{ad}}{dt}\right)(L+C_v(T_{des}-T_c))
\end{align*}
\]

In the equation (2), the left side gives the amount of sensible heat of the silica-gel (s), water (w) and the heat exchanger (h) metal part during the adsorption or desorption process. \(\delta\) and \(\gamma\) term for adsorbent functions as desorber or adsorber and whether hex is connected to the evaporator or with another hex. This term consider the sensible heat input / output required according to the stages of the cycle process. Heat release from adsorption and heat input from desorption are mention in the first term on the right side. The sensible heat adsorbed from steam is mention in seconds terms on the right side. The total amount of heat released into cooling water after the adsorption process or provided by hot water for the desorption process mention in the last term on the right side. In the equation 3, the sensible heat needed by liquid refrigerant and metal tube heat exchanger in the evaporator show in the left side. The total amount of heat from cold water states in the first term on the right side. The latent heat of evaporation (L) for the amount of adsorbed refrigerant (\(dq_{ads}/dt\)) and the sensible heat needed to cool the incoming condensate from the \(T_{con}\) condensation temperature to the \(T_{eva}\) evaporation temperature mention in the second term. In the equation 4, the sensible heat needed by liquid refrigerant and metal tube heat exchanger in the condenser show in the left side. The amount of heat released into the cooling water states in the first term on the right side. The latent heat of evaporation (L) for the amount of refrigerant absorbed (\(dq_{des}/dt\)) and the amount of heat carried by the liquid condensate when it leaves the condenser to the evaporator mention in the second term.

2.1.3. Performance equation

The performance equation, coefficient of performance (COP) and cooling capacity (CC), of the adsorption cycle can be measured as:

\[
\text{COP} = \frac{\dot{m}_cha \int_{0}^{\text{cycle}} (T_{ch,i}-T_{ch,o}) \, dt}{\dot{m}_hw \int_{0}^{\text{cycle}} (T_{hw,i}-T_{hw,o}) \, dt}
\]

\[
\text{CC} = \dot{m}_cha \int_{0}^{\text{cycle}} (T_{ch,i}-T_{ch,o}) \, dt / t_{\text{cycle}}
\]

| Symbol | Value | Unit |
|--------|-------|------|
| \(C_s\) | 924 | J/kgK |
| \(C_v\) | 1.89E+03 | J/kgK |
| \(C_w\) | 4.18E+03 | J/kgK |
| \(D_o\) | 2.54-4 | m²/s |
| \(E_a\) | 4.20E+04 | J/kg |
| \(L_w\) | 2.50E+06 | J/kg |
| \(Q_s\) | 2.86E+06 | J/kg |
| \(R\) | 8.314 | J/kgK |
| \(R_p\) | 3.00E-04 | m |
| UA_{ads} | 2001 | W/m²K |
| UA_{des} | 2233 | W/m²K |
| UA_{eva} | 2360.75 | W/m²K |
| UA_{con} | 4061.86 | W/m²K |
| \(W_s\) | 16 | kg |
| \(W_{con,w}\) | 5 | kg |
| \(W_{eva,w}\) | 25 | kg |
3. Results and discussion

3.1 Variation of slope angle position on voltage output

Figure 2 shows a comparison of the voltage value coming out from photovoltaic with three different slope angle positions to the east. The time of data collection starts at 8:30 a.m. until 16:00 p.m.

As can be seen on the graph that the value of the voltage increase from the beginning until 11.00 a.m. However, when the time shows 11.30 hours up to 12.00 hours, the voltage shows a stable value with the largest voltage value is 15.1 V at the slope angle of 15°. There are fluctuation values in the rest of time but the tendency shown decreased slightly.

3.2 Variation of temperature and water content in hex

Figure 3 and Figure 4 shown the variation of the temperature and water content on the hex during one cycle of the two adsorbent beds (hex) with distribution time of desorption and adsorption (840s), pre-heating and pre-cooling (60s), total cycle time (900s) and heat source temperature is 70 °C. In addition, both of this figure clarifies whether the simulation program that is carried out is in accordance with the steps of the work process in the adsorption system.
Figure 3. Temperature distributions on the hex

Figure 3 informed that in the beginning (420s) heat exchangers is in desorption process. In this process, hex operates in condenser pressure in which the refrigerant will be released and condensed in condenser. Afterwards, hex is cooled down by cooling water (pre-cooling) and heated up by hot water (pre heating). During this 30s process, refrigerant circulation is stopped due to valves are in closed position. In this process, the hex’s temperature will decrease because of cooling process and will increase because of heating process, respectively. Since the pre-cooling process end, then the adsorption process starts. In the adsorption process, hex operates in evaporator pressure and refrigerant in evaporator will be evaporated and adsorbed by hex.

Figure 4. Water content distributions on the hex

Based on the figure 4, water content decreased and increased during desorption and adsorption process respectively. Water content were constant during pre-cooling and pre-heating process because all valves in teh system in closed position.

3.3 Performance characteristic
Figure 5 informed the performance characteristic of the adsorption refrigeration cycle. Heat source temperature range from 50 °C to 80 °C arranged in order to gain the suitable performance of the system. Parameter condition based on Table 2 are implemented during simulation.

![Figure 5. Performance characteristic of the cycle](image)

Generally, the performance of the cycle, in both cop and cooling capacity, increased along with heat source temperature. For heat source temperature 50°C to 55°C, the performance in both cop and cooling capacity is too small. It means that during this range of temperature, the system did not work properly because the processes of desorption and adsorption could not be done. The cycle seems to be work properly in the heat source temperature 60°C. By this point of view, the adsorption refrigeration system that is offered in this research can only work in that minimum heat source temperature.

4. Acknowledgment
On this occasion we would like to prolong our gratitude to Directorate Jenderal of Higher Education of Indonesia and Center for Research and Community Service (P3M) Bali State Polytechnic for the main and supporting funding of this research and to the Head of Bali State Polytechnic for administrative support for the velvetiness of this research. We also thankfulness to colleges and students who provide assistance either directly or indirectly.

5. Summary
Based on the present study, there are some concluding remark can informed i.e.:

1. The largest voltage value released by the photovoltaic array is 15.1 V at the slope angle of 15°.
2. The adsorption cycle work properly minimum at low heat source temperature 60°C.
3. The performance of the cycle, in both cop and cooling capacity, increased along with heat source temperature.

6. References
[1] Dieng A O, Wang R Z, 2001 J. Renewable and Sustainable Energy Reviews, 5 313
[2] Sakoda A and Suzuki M, 1984 J. Chemical Engineering of Japan, 17 52
[3] Alam K C A, Khan M Z I, Uyun A S, Hamamoto Y, Akisawa A and Kashiwagi T, 2007 J. Applied Thermal Engineering, 27 1686
[4] Khan M Z I, Alam K C A, Saha B B, Akisawa A and Kashiwagi T, 2007 *J. Applied Thermal Engineering*, 27 1677
[5] Karagiorgas M, Meunier F, 1987 *J. Heat Recovery Systems and CHP*, 7 285
[6] Ng K C, 2003 *J. Heat Transfer Engineering*, 24 1
[7] Wirajati I G A B, Ueda Y, Akisawa A and Miyazaki T, 2016 *Heat Transfer Engineering*, 37 606