Research Article

Experimental Investigation on an Absorption Refrigerator Driven by Solar Cells

Zi-Jie Chien, 1 Hung-Pin Cho, 2 Ching-Song Jwo, 1 Chao-Chun Chien, 1 Sih-Li Chen, 2 and Yen-Lin Chen 3

1 Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, Taipei 10608, Taiwan
2 Department of Mechanical Engineering, National Taiwan University, Taipei 10617, Taiwan
3 Department of Computer Science and Information Engineering, National Taipei University of Technology, Taipei 10608, Taiwan

Correspondence should be addressed to Yen-Lin Chen; ylchen@ntut.edu.tw

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This experiment is to study an absorption refrigerator driven by solar cells. Hand-held or carried in vehicle can be powered by solar energy in places without power. In the evenings or rainy days, it is powered by storage battery, and it can be directly powered by alternating current (AC) power supply if available, and the storage battery can be charged full as a backup supply. The proposed system was tested by the alternation of solar irradiance 550 to 700 W/m² as solar energy and 500ml ambient temperature water as cooling load. After 160 minutes, the proposal refrigerator can maintain the temperature at 5–8 °C, and the coefficient of performance (COP) of NH₃-H₂O absorption refrigeration system is about 0.25. Therefore, this system can be expected to be used in remote areas for refrigeration of food and beverages in outdoor activities in remote and desert areas or long-distance road transportation of food or low temperature refrigeration of vaccine to avoid the deterioration of the food or the vaccines.

1. Introduction

Nowadays the economic development has resulted in a lot of energy exploitation, and the oil reservation becomes exhausted. It will run out within less than 50 years, causing the so-called energy crisis. Overexploitation has also caused increasingly serious global warming problem. Many advanced countries in the world today take the lead in promoting the research and development of alternative energy such as wind energy, solar energy, and biomass energy. The importance of research and development on green energy has attracted much attention. Although their cost is high, continuous research and development will achieve the stable, easy-to-use, and reasonably priced alternative energy in some day. This is a road we must take for the survival of humanity.


In summary of the previously mentioned literature review, the proposed small-scale absorption refrigeration system driven by solar power is unprecedented. This study proposes an absorption refrigeration system using refrigerant NH₃ and absorbent H₂O. As being an environmentally friendly refrigeration system, it is powered by solar cells. The successful development of the proposed system can solve problems such as the long-distance transportation of medical vaccines and the refrigeration of food and beverages in remote areas lacking power supply.

2. Experiment and Methodology

2.1. The Proposed Experimental System. As shown in Figure 1, the energy of the absorption refrigeration is supported by 18 V of direct electricity from solar cells and the capacity of cold storage covers in 30 liters. Power consumption covers 1.2 KWH/24 h with filling 70 grams of NH₃ refrigerant. The experimental system is the NH₃–H₂O absorption refrigeration system consisting of solar cells, controller, storage battery, rectifier, and absorption refrigerator. In the daytime, the solar cells receive solar energy to power the absorption refrigerator. When too much energy is supplied, the controller will store the excess energy in the storage battery. When the solar power is insufficient or unavailable at night or in cloudy days, it depends on the storage battery for power supply. The storage battery can be charged in places with AC power supply as a backup power source. In order to achieve better power generation efficiency of the solar panel, it will always be placed towards the sun. The shape between solar panel and horizontal line becomes tilt angle. The optimal angle for tilted surface was calculated by searching for the values of which the daily total solar radiation was at a maximum for a specific period. The yearly average optimal tilt angle for a south-facing solar collector about 31.21 to 34.31 degrees [28]. Therefore, the tilt angle of the study is determined as 35°C.
2.2. The Proposed Experimental Method and Procedures. The location of installation of various measurement points, data acquisition device, and personal computer connection of the experimental system are shown in Figure 2. We applied a data logger and a computer to collect six points of data that set sample time to two minutes. These six points include four temperatures points (i.e., ambient temperature, generator temperature, cooled side temperature, and water temperature), one current of solar cell, and one solar irradiate.

We conduct the no-load test at first and then the loaded tests while gradually recording the experimental results. The major test of this study is to test the performance and feasibility of running the absorption refrigeration system by using the power generated by solar cells during the day. Regarding the backup battery power supply performance and the charging system’s material characteristics are not discussed in this study.

The experimental system’s solar cells and storage battery, absorption refrigerator specifications are shown in Table 1. The maximum power capacity of the solar cells is 184 W. The maximum storage capacity of the storage cell is 100 Ah. The refrigerant of the absorption refrigeration system is NH₃ and the absorbent is H₂O. The input power voltage is 17 V, and the input power is 65 W.

### Table 1: Specifications of solar cell driven absorption refrigerator.

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array of solar cell</td>
<td>The area of solar cell, $A$</td>
<td>1.78 m²</td>
</tr>
<tr>
<td></td>
<td>Max output power of solar cell, $P_{\text{max}}$</td>
<td>184 W</td>
</tr>
<tr>
<td></td>
<td>Solar irradiance, $S$</td>
<td>800 Wm⁻²</td>
</tr>
<tr>
<td></td>
<td>The efficiency of energy conversion from solar energy to electric power</td>
<td>0.14</td>
</tr>
<tr>
<td>Storage battery</td>
<td>Stands for the battery storage capacity</td>
<td>100 AH</td>
</tr>
<tr>
<td></td>
<td>Electric consumption</td>
<td>22 AH/day</td>
</tr>
<tr>
<td></td>
<td>The number of day without sunshine</td>
<td>2 days</td>
</tr>
<tr>
<td></td>
<td>The maximum degree of electric discharge</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>The efficiency of the storage battery</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>The loss coefficient of the circuit</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>The correction coefficient of temperature</td>
<td>0.9</td>
</tr>
<tr>
<td>Absorption refrigerator</td>
<td>Refrigerant</td>
<td>NH₃</td>
</tr>
<tr>
<td></td>
<td>Absorption</td>
<td>H₂O</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>65 W, 17 V</td>
</tr>
</tbody>
</table>

3. Theoretical Formulation for Transformer

The performance of the solar cells and absorption refrigeration system can be obtained by the following equation.
The output of power supply capacity of solar cells [2] is calculated by the following equation:

\[ P_{\text{solar}} = S \Delta \eta_{PV}, \]  

where \( P_{\text{solar}} \) is power supply capacity of solar cells (W), \( S \) is solar irradiance (W/m\(^2\)), \( \Delta \) is the area of Solar array to receive solar irradiation (m\(^2\)), and \( \eta_{PV} \) is the efficiency of energy conversion from solar energy to electric power.

According (1), the power generation of the solar panel is proportional to the solar irradiance.

The coefficient of performance (COP) of absorption refrigeration system [3] is

\[ \text{COP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{Q_{\text{gen}}} \left(1 - \frac{T_a}{T_g}\right) \left(\frac{T_r}{T_a - T_r}\right), \]  

where \( Q_{\text{gen}} \) is heat energy given to the generator in absorption (W), \( Q_L \) is heat energy that evaporator absorbs from the cooled space (W), \( T_a \) is the ambient temperature (K), \( T_g \) is the generator temperature (K), and \( T_r \) is the cooled side temperature (K).

We could get several trends from (2); namely, as \( T_g \) increases, the COP increases; as \( T_a \) increases, the COP decreases.

4. Results and Discussion

In the no-load test of the absorption refrigeration system, we conducted the 100-minute experimental test and record the experimental results in Figures 3–5 before carrying out the 200-minute loaded experimental test. The test results were recorded in Figures 6–8, and the theoretical relationship equations were applied for analysis to get the following:

Under the sun, the ambient temperature is 30°C, and the cold side temperature is 24°C. The trend of cold side temperature is shown in Figure 3. When solar panels are under the sunlight, the absorption refrigeration system will start to run. It can be apparently found that the cold side temperature slowly decreases. After running for 30 minutes, the cold side temperature dropped to 10°C. After 70-minute running, the cold side temperature dropped to 5°C.

As shown in Figure 4, due to changes in solar irradiance, the power supply 880 W/m\(^2\) dropped to 770 W/m\(^2\) after 90 minutes. The solar panel output voltage remains between 16.9 and 17.5 V. At the moment of 35 minutes, the sunlight covered by clouds leads to the deep drop of voltage. However, to reveal the real experimental situation, we still keep these data unaltered in Figure 4.

As shown in Figure 5, when the ambient temperature remains unchanged, the cold side temperature dramatically dropped to below 5°C after running for 70 minutes. Due to the decrease in cold side temperature, the absorption refrigeration system COP dropped from 0.5 to 0.28, the refrigeration system cooling capacity dropped from 69 W to 39 W, proving that the cooling capacity will decrease over declining cold side temperature and its COP will also decrease.
Figure 6: The changes in the temperature of 500 mL water placed inside, under the sunlight.

The loaded test was to place the 500 mL room temperature water inside as shown in Figure 6. When the testing ambient temperature was 27°C, the cold side temperature slowly dropped to 24°C. After running for 20 minutes, the cold side temperature dropped to 13°C, after running for 100 minutes, the cold side temperature dropped to 5°C. The water temperature dropped very slowly from the beginning temperature of 24°C. After 80 minutes, the water temperature apparently dropped. After 200 minutes, the water temperature dropped to 8°C and would be even lower if the system was still running on.

The study investigates the alternation of solar irradiance measured every two minutes while driving on the highway, which results in a sudden transform of solar irradiance. The solar irradiance and output voltage changes are shown in Figure 7. When the solar irradiance is 550 to 700 W/m², the output voltage is about 16 to 17.2 V. In other words, when the solar irradiance rate is greater, the solar power generation will be greater. According to (1), the power generation of the solar panel is proportional to the solar irradiance. The results confirm the phenomenon given in (1).

As shown in Figure 8, under the sunlight, 500 mL water of room temperature is placed inside. At 0–60 minutes, water temperature from 24 to 21°C, and cold side temperature from 24 to 8°C as shown in Figure 6, cooling load is high. COP drops rapidly from 0.38 to 0.22, and the refrigerating capacity drops rapidly from 65 to 48 W. At 60–160 minutes, water temperature from 21 to 12°C, and cold side temperature from 8 to 5°C mean cooling load decreases but it is still high, the system COP is around 0.22 and the refrigerating capacity is about 45 W. At 160–200 minutes, the water temperature from 12°C to 10°C, and cold side temperature of 5°C, mean cooling load is low as shown in Figure 6 and the system COP increases from 0.22 to 0.28.

Figure 7: The changes in output voltage and solar irradiance, when 500 mL was placed inside, under the sunlight.

Figure 8: The changes in refrigeration system COP and refrigerating capacity Qc, when 500 mL water of room temperature is placed inside, under the sunlight.

5. Conclusions

In summary of the experimental research results, the solar energy can supply energy for the running of the absorption refrigerator. The outdoor activities and works, such as mineral development, road construction, and other occasions, can be adopted. It is designed in order to meet the outdoor usage requirements as lightweight, low price, and day and night usage. According to the experimental results, the alternation of solar irradiance 550 to 700 W/m² and 500 mL ambient temperature water as cooling load. After 160 minutes, the proposal refrigerator can maintain the temperature at 5–8°C, and the COP is about 0.25.
Acknowledgments

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