Simulation of a Double-Effect Solar Absorption System for Traditional House In Yemen.

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Abstract: During the last few years, the awareness of the pollution and the global warming has dramatically increased which encourage the researchers around the world to find an alternative source of energy. One of the most efficient sources of energy is the solar energy especially for cooling and heating applications. This paper, described the simulation of a double-effect solar absorption system in Yemen using water lithium bromide solution as a working fluid. The system will be applied to a typical traditional house in Yemen. The performance of the system will be analyzed based on different high pressure generator temperature for the yearly solar radiation data. At higher pressure generator temperature, the results show a higher coefficient of performance of the system. This simulation also estimate high pressure generator heat transfer required to operate the system. As a result, the size of solar collector area and the cost of such system will be calculated.

1.0 Introduction

The Yemen's electricity consumption has reached 4.70 billion kilowatt per hours in 2010. Air conditioning is the biggest energy consumer in Yemen. In fact, 21% of the total consumption goes for the air conditioning. Yemen is considered as one of the smallest oil producer in the world and electricity generation is draining the government’s budget. So, to reduce the energy demand for the air conditioning, engineers have to come up with alternative solutions. One of the alternatives is using know-how building design concept. This concept is helps to reduce the energy consumption for cooling. Other solution is using the solar energy as a power source instead of the hydrocarbons. Solar energy is very functional in term of environment and economy [1, 2, 3].

In the aspect of air conditioning, solar energy can be used in two ways: solar photovoltaic (PV) air conditioning and solar thermal air conditioning. The concept of the solar PV air conditioning is converting the solar energy to an electrical energy by solar panels to drive the chiller. On the other hand, in the solar thermal air conditioning, solar energy is used as a heat source to drive the chiller. This paper deals with the solar thermally driven air conditioning technology. This project aims to design double-effect solar air conditioning for a traditional house in Yemen, to evaluate the performance of such a system, and finally to calculate the cost of such system.

2.0 Methodology

2.1 Cooling Load Estimation

This work aims to simulate a solar air conditioning system for residential usage. The simulation will be done on a typical traditional house in Yemen. The plan of traditional Yemeni house is shown in Figure 1. Firstly, the cooling load for the typical Yemen’s house, shown in Figure 1, is calculated using Cooling Load Temperature Deferential/Cooling Load Factor (CLTD/CLF). This method is derived from the Transfer Function Method (TFM) and uses tabulated data to simplify the calculation [4].

\[
Q = Q_{\text{glass}} + Q_{\text{lighting}} + Q_{\text{wall}} + Q_{\text{roof}} + Q_{\text{lighting}} + Q_{\text{ventilation}} + Q_{\text{people}} + Q_{\text{people}}
\]  

(1)

Where \( Q \) is the cooling load which was calculated and found to be 20 kW.
2.2 Solar Absorption System Modeling

In Figure 2, solar absorption air conditioning system consists of two main systems which are solar collector and absorption circulation. Detail on the double-effect solar absorption air conditioning system are given in Rasih and Ani [5].

2.2.1 Solar Radiation in Yemen

In this project, the non-concentrated type collectors are used over the concentrated type due to the high cost of the concentrated collectors. Under steady conditions, the amount of useful heat absorbed by a solar collector is equal to the energy absorbed in the heat transfer fluid minus the direct and indirect heat losses from the surface to the surroundings. This relation can be described by the solar collector efficiency, \( \eta_{\text{col}} \) and collector heat gain, \( Q_u = (\eta_{\text{col}})A(G) \), where \( G \) is the solar radiation values (kW/m\(^2\)), \( \eta_{\text{col}} \) is the solar collector efficiency, \( A \) is the solar collector surface area (m\(^2\)) [6, 7, 8]. The annual average daily solar radiation is given in Table 1.

**Table 1: The annual average daily solar radiation values, \( G \) (KW/m\(^2\)/day) for each city.**

<table>
<thead>
<tr>
<th></th>
<th>Sana'a</th>
<th>Boun</th>
<th>Hodeidah</th>
<th>El Khaber</th>
<th>Taiz</th>
<th>Macha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>5.97</td>
<td>5.92</td>
<td>6.03</td>
<td>6.07</td>
<td>5.96</td>
<td>5.28</td>
</tr>
<tr>
<td>Feb</td>
<td>6.69</td>
<td>6.65</td>
<td>6.73</td>
<td>6.77</td>
<td>6.62</td>
<td>5.90</td>
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</tbody>
</table>
2.2.2 Absorption Circulation

Equilibrium property correlations from literature are taken for water and lithium bromide-water solution. These correlations are required to obtain temperatures, pressures, enthalpies, and concentrations at various states of the system for water vapor and lithium bromide-water solution. Detail expression for the mass and energy balances for condenser, evaporator, absorber, generator and coefficient of performance could be obtained in Rasih and Ani [5]. All the equations are solved simultaneously using MATLAB software.

2.0 Results and Discussion

The system should be capable to provide approximately 20 kW based on the cooling load calculation. The simulation take place by assuming that the pressure of the high pressure generator is 100 Kpa, the absorber temperature is be 30°C, the condenser temperature is assumed to be 40 °C, the evaporator temperature is assumed to be 10 °C, and the heat exchangers efficiencies are 60 %. It is clearly noticed from Figure 3 that the COP is directly proportional to the $T_{hpg}$ with saturated value of 1.31. In other words, the COP increase with the increasing of $T_{hpg}$. In the other hand, as shown in Figure 4, the concentration of the LiBr solution is also directly proportional to $T_{hpg}$. As the crystallization limit for LiBr is around 70 %, $T_{hpg} \geq 160 °C$ can't be used for the safety of the system. As a results of all that, The most suitable $T_{hpg}$ is 155 °C.

![Figure 3: Coefficient of performance vs high-pressure generator, $T_{hpg}$](image)

![Figure 4: LiBr concentration limitation vs high-pressure generator, $T_{hpg}$](image)
The MATLAB code used in the simulation of this system obtained the parameters $Q_{hpg}$, $Q_{con}$ and $Q_{abs}$ are 15.44 kW, 24.49 kW, and 10.89 kW respectively. According to the previous results, the $Q_{hpg}$ needed to operate the system is 15.37 KW. As a solar absorption system, the $Q_{hpg}$ will be obtained from the solar energy. The energy transformation from solar radiation will transfer by using solar collectors. Evacuated tube solar collectors will be used to generate heat for the high pressure generator. To calculate the area needed to generate the required $Q_{hpg}$, Equation 1 is used. The average solar collector area required to operate the system is listed in Table 2.

<p>| Table 2 : Estimated solar collector specific area (m$^2$) for selected locations of Yemen. |
|------------------------------------------|----------------|----------------|----------------|-----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Average specific area (m$^2$)</th>
<th>Sana'a</th>
<th>EL Boun</th>
<th>Hodeidah</th>
<th>El Khaber</th>
<th>Taiz</th>
<th>EL Macha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average specific area (m$^2$)</td>
<td>93</td>
<td>94</td>
<td>93</td>
<td>93</td>
<td>95</td>
<td>107</td>
</tr>
</tbody>
</table>

4.0 Conclusions

The application of solar energy in air conditioning system required continuous improvement to make it available and practical for the commercial utilisation. The simulation of solar absorption system in this study provides good tools to identifying the parameter or components of water lithium bromide solution. Besides that, the maximum COP and generator temperature and have been evaluated. Cooling load calculation should be done initially in designing the system. Based on the data from the simulation, the best high pressure generator temperature is 155°C, higher temperature then this will cause crystallization. For solar energy extraction, the heat required to operate the system will be obtained by using thermal solar collector. The specific area required for the solar collectors depend on the solar irradiance of the location and the design of solar collector type. Based on the economic analysis, it shows that the high cost of the system is the main constraint for the application since the conventional system is much cheaper.

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References