Performance of a single effect absorbing chiller lithium bromide-water coupled to a solar collector

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Abstract. In this study, the potential of using solar energy which would be catch by a flat plate heat exchanger is investigated as the input source of heat to a single absorption refrigeration system of lithium bromide-water. Validating the simulation, results was compared to the theoretical and empirical results of previous studies. The daily operation of the refrigeration system for atmospheric data in Tehran's typical day, shows that there would be an optimum number of flat plate collectors in the solar absorption system, which is 50 with a surface area of 5/38 square meters. This number, in addition to have a proper performance factor, can provide a cooling load of about 5 kilowatts, while the power consumption of pumping in the combined cycle is not considerable. Finally, the effect of different performance parameters including temperature of the heat generator, evaporator temperature on the daily efficiency of the solar refrigeration cycle has been investigated. As the evaporator temperature increases, the daily performance of the solar refrigeration system is increased.

Keywords: solar collector, solar energy, refrigeration system, lithium bromide-water.

1. Introduction

People every day spend a large proportion of their time in a closed environment (whether home or work environment), it is necessary to provide them with comfortable thermal condition. The preparation of these thermal conditions has attracted the attention of many scientists. One of the systems for providing such environment is absorption chiller. Refrigeration systems today are also of great importance in the food, oil, petrochemical industry, and etc. due to the need for low temperatures, so these industries also need Absorption chillers. The fundament of absorbing refrigeration systems is depended and based on the Michel Faraday experiment, which was carried out in 1824 [1]. Considering this fact, trying to convert to clean and renewable energies is of paramount importance because they are also justified in terms of environmental economic benefits. Between 30-50% of the world's total energy consumption is used to cool and heat buildings, so increasing the efficiency of these systems, which results in less energy consumption, is of crucial importance [2].

Most solar absorption systems around the world are based on a single-effect chiller and a decent center. plate or discharge drain collector. Floresides et al. In 2002, a simulation of a single-effect absorption chiller was carried out by the solar thermal collectors under the Cyprus climate and determined the optimal design of the system by changing the main solar design variables, such as the collection site and the volume of the storage tank [3]. Asli Zadeh et al. carried out a similar study in 2005, in which a combination of ETC modules...
and a Single effect-absorption chiller were analyzed to examine the cooling demand of a typical building in Malaysia. This research reveals that one ton of refrigeration needs 35 square meters of solar vacuum tube collector [4].

In 2009, Kushik and Aurora studied the effect of generator temperature, absorber and evaporator on the energetic and exergetic efficiency of absorption systems. The researchers reported variations in the coefficient of performance of the single absorption system which ranged between 0.6 and 0.75 and the variations in the coefficient of performance of the absorption system of the diphtheria between 1 and 28/1. The results of the study also include the heat transfer values for all components of a single absorption chiller such as evaporator, assembler, condenser and generator, pump operation and performance factor [5].

Pitroska et al. replaced two absorbing chillers centralized collectors with standardized systems and implementing it for the office building in Cairo. The results clearly state that chillers with two thermal and cold effects are not necessarily better than cooled chillers. It has also been shown that the energy of solar cooling systems is about 38- 54% more efficient than condensing chillers [6].

Mitt et al. used an entropy analysis to analyze the performance of an absorption refrigeration system. The figure below shows the absorption chiller which was studied in this research. Their results indicate that the lowest entropy production follows the highest yield coefficient in the absorption cycle [7].

Martinez et al. tried to design single-effect absorbing chillers with low capacity and with various types of solar collectors. They found that the drainage collector was the best way to collect chillers because of their higher efficiency than single-plate assembly [8].

Gemery et al. analyzed a single-effect-absorbing chiller with a pre-heater gas, and a wide range of high-performance with high energy levels was achieved. It was concluded that a solar chiller, supported by a gas burner, is more environmentally friendly than a conventional gas-absorbing gas. But he did not investigate whether this configuration actually consumes less primary energy or, if economically feasible [9].

Shirazi et al. analyzed the alternatives of the various backup systems for single energy absorption receivers along with solar thermal collectors. The results showed that the system using a gas backup system significantly consume lower energy in comparison with those using a mechanical chiller with electric motor support [10].

Plows et al. analyzed and optimized the performance of a chiller absorbed by a Nano-fluid-based solar collector. The average thermal efficiency increase by using nesosilicates is roughly 2.5%. The system is usually optimized on a daily basis for operations with pure water and Nano fluid. According to the final results, the use of Nano-liquids in the solar collector can increase the system's performance by nearly 4.0 percent and increase refrigeration by about 0.84 percent daily [13].

Peltla et al. analyzed the energy and exergy of a chiller under solar thermal conductivity under extensive boundary conditions. Analysis identified sensitivity recognition, which represents the most important
parameters of the change in efficiency and irreversible distribution. According to the findings, the COP design of the chiller is 0.4, while the extrusion efficiency is 0.26. The solar collector component is most affected by the destruction and loss of exergy in the entire cycle [14].

Previous studies generally discussed simulations, energy analyzes and economic analyzes of single charge absorption, while the heat input was assumed constant in the cycle. In some other studies, a waste heat recovery and use in chillers are discussed, but there was no comprehensive energy analysis. In the current study, the simulation, energy analysis of the use of solar absorption chiller is discussed.

2. Method of study
As shown in figure 1, the single-effect-absorption refrigeration system and the associated control volume. Also it could be drawn from Fig. 1 that the main components of the solar absorption system are evaporator, absorber, condenser, heat generator, solvent expansion valve, refrigerant expansion valve, pump and collector.

![Figure 1. Schematic of Chiller Absorption.](image)

The vital equations for determining the parameters are obtained by writing the conservation of mass equation and first thermodynamic law for different components of the refrigeration cycle. The general form of the equations of mass survival, the concentration and the first order of thermodynamics in the permanent state are presented as follows [15]. In these equations:

- $m$ is mass flow,
- $x$ is concentration of lithium bromide in solution,
- $h$ is enthalpy and $in$ and $out$, indicates the flow of input and output in the volume of control, respectively.

\[
\sum \dot{m}_m = \sum \dot{m}_out \tag{1}
\]
\[
\sum (\dot{m}x)_m = \sum (\dot{m}x)_{out} \tag{2}
\]
\[ \sum \dot{Q} - \sum \dot{W} = \sum (\dot{m} h)_{\text{out}} - \sum (\dot{m} h)_{\text{in}} \]  

(3)

The values of \( T_3 \) and the following equations are obtained [16]:

\[ T_3 = T_i + E_L \frac{x_i C_{p,4}}{x_4 C_{p,4}} (T_4 - T_i) \]  

(4)

Now, by obtaining the heat capacity of the solution at points 3 and 12, using their temperature, the solvent temperature at point 11 can be obtained by equation (5)[17].

\[ T_{11} = T_i + E_L \frac{x_i C_{p,12}}{x_{12} C_{p,3}} (T_{12} - T_i) \]  

(5)

The soluble temperature at points 5 and 13 is also obtained by relations (6) and (7), respectively.

\[ T_5 = T_i + E_L (T_4 - T_2) \]  

(6)

\[ T_{13} = T_{12} - E_L (T_{12} - T_i) \]  

(7)

The fluid temperature at points 13 and 14 can be considered equal. With the assumptions and calculations that have been done so far, the thermodynamic conditions of all points in the absorption cycle have been determined. Using the energy conservation law for the low-pressure generator, the accuracy of the amount of concentration of the solution from the high-pressure generator can be verified. In fact, trial and errors must continue until the energy conservation law is established in the low pressure generator. After the energy conservation in the low-pressure generator is achieved, and by obtaining the point enthalpy 2, using the equation (8), the power absorbed by the absorption chiller pump is obtained from equation (9).

\[ h_2 = h_1 + v_1 \left( \frac{P_2 - P_1}{\eta_p} \right) \]  

(8)

\[ \dot{W}_{p,ac} = \dot{m}_1 (h_2 - h_1) \]  

(9)

Finally, the thermal power generated in the condenser and the absorber, the heat power consumed in the high-pressure generator and the coefficient of absorption chiller performance are calculated by relations (10) [18, 19]:

\[ \text{COP} = \frac{\dot{Q}_{eva}}{\dot{Q}_{reg} + \dot{W}_{p,ac}} \]  

(10)

The solar heat is the source of energy required by the generator in a solar absorption chiller which would be absorbed by the drainage tube collectors. But since access to this source of heat is influenced by various factors such as the cloudiness of the sky, then an auxiliary heater should be used to provide the required heat deficiency for the generator. With this explanation, solar collectors and auxiliary heater are considered as sources of generator heat supply.

\[ \dot{Q}_{acc} = \dot{Q}_{gen} - \dot{Q}_{solar} \]  

(11)

The amount of solar energy received is proportional to the collector’s efficiency and is obtained from the following equation:
\[ \dot{Q}_{solar} = \eta_{\text{collector}} \cdot A_{\text{collector}} \cdot G \]  

(12)

The collector efficiency is defined as follow:

\[ \eta_{\text{collector}} = a_0 - a_1 \frac{\Delta T}{Gt} - a_2 \frac{\Delta T^2}{Gt} \]

\[ \Delta T = T_{\text{gen}} - T_{\text{a}} \]  

(13)

The coefficients are constant for each collector and are obtained after many experiments performed on them.

3. Results and discussion

The results include heat transfer values for all components of a single absorption chiller such as evaporator, assembler, condenser and generator, pump operation and coefficient of performance, which is compared with the results of this study. The comparison of the average relative error is calculated by the following equation:

\[ \text{Er} = \left| \frac{X_{\text{exp}} - X_{\text{sim}}}{X_{\text{exp}}} \right| \times 100 \]

where \( X \) is the simulation and experimental values of the parameters.

Table 1 compares the results of the present study with the study of Kushik and Aurora. The input parameters for simulating Single effect-absorption chillers are as follows [4]:

- \( T_{\text{gen}} = 87.8^\circ\text{C} \), \( T_{\text{eva}} = 7.2^\circ\text{C} \), \( T_{\text{con}} = T_{\text{abs}} = 37.8^\circ\text{C} \), \( E_L = 0.7 \), \( m_r = 1 \text{ kg/s} \),

In the research of Kushik and Eura, the efficiency of the chiller pump is not mentioned. This amount is considered 95% in this research.

| Energy Flow (kW) | Part             | symbol    | Current study | Kuashik and Aurora[5] |
|------------------|------------------|-----------|---------------|-----------------------|
| Error (%)        |                  |           |               |                       |
| 0/14             | 3100/2           | 3095/70   | \( \dot{Q}_{\text{gen}} \) Generator |
| 0/08             | -2942/9          | -2945/27  | \( \dot{Q}_{\text{abs}} \) Absorber   |
| 0/30             | -2513/5          | -2505/91  | \( \dot{Q}_{\text{con}} \) Condenser |
| 0/03             | 2356/2           | 2355/45   | \( \dot{Q}_{\text{eva}} \) Evaporator |
| 8/39             | 0/3405           | 0/0314    | \( W_p \) Pump |
| 0/11             | 0/7600           | 0/7609    | COP Efficiency Coefficient |

Significant input design parameters for absorption chillers in this study, which is related to residential complex with 425 m² area in Tehran province, with the following schematic:
Unique absorption chiller

\[ \dot{Q}_{\text{evu}} = 65\text{kW}, \quad T_{\text{con}} = T_{\text{abs}} = 35^\circ \text{C}, \quad E_L = 0.7, \quad T_{\text{eva}} = 5^\circ \text{C}, \quad T_{\text{gen}} = 90^\circ \text{C} \]

In figure 2, the values of the system's performance coefficient in terms of generator temperature are shown for the evaporator temperature for a single absorber chiller.

As shown in figure 2, the coefficient of absorption chiller performance increases with evaporation temperature at a constant generator temperature. As the evaporator temperature increases, the refrigerant enters the absorber increases. Also, after solving the equations of mass conservation and cyclic analysis, the heat transfer rate of the input to the generator decreases and, therefore, according to equation (11) and with constant evaporation heat transfer rate, the coefficient of performance goes up.

Figure 2. Generic absorption chiller performance coefficient in terms of generator temperature for different values of evaporator temperature.

As shown in figure 3, if the number of solar collectors increased 20% in, the mass flow in a solar collector assembly would increase by about 50%. This illustrates that selecting the optimal number of solar collectors is of paramount importance, so that by increasing this number to more than 50, the mass flow rate and power consumption of pumping will increase.

Figure 3. Simulation values of electric power generation.
In figure 4, the effect of evaporator temperature change on the coefficient of performance of the refrigeration system is shown in terms of the time of day.

As shown in figure 4, the performance coefficient of the absorption refrigeration system increases throughout the daytime by increasing the temperature of the evaporator from 5 °C to 15 °C. An increase in the temperature of the evaporator will increase the enthalpy of the outlet stream from the evaporator and thereby increase the cooling rate available in the evaporator and increase the refrigeration coefficient of the system.

4. Conclusion
In this study, the performance of a single absorption refrigeration system of lithium bromide-water was investigated in order to investigate the possibility of using solar collectors as an input source for generators. The effect of different functional and design parameters on the performance coefficient of the hybrid system was studied. The overall results obtained from the present study are as follows:

1. Performance coefficient of the studied system varies between 0.65 to 0.75
2. at the same generator temperature, the performance coefficient of a single absorber chiller increases with increasing evaporator temperature.
3. The absence of solar radiation during all day and night hours can be used as an auxiliary cycle in conjunction with conventional refrigeration cycles during sunny days.

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