Investigations on Solar Powered Vapour Absorption Refrigeration based Air Conditioning

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ABSTRACT
A solar-operated vapor absorption refrigeration cycle is environment-friendly refrigeration system that holds the potential to be used for refrigeration and air conditioning systems. Such a system requires a solar concentrator to run the vapor absorption refrigeration cycle using LiBr-H₂O-based refrigeration/air conditioner for small capacity applications. With the solar-powered pumping process, this refrigeration system becomes completely free from electricity requirements. However, the limitations of all time solar radiation availability, low-pressure maintenance requirement of the LiBr-H₂O system, low efficiency, and low COP as compared to other vapour compression refrigeration based air conditioning system are the key deterrents. In the present study, the modeling and analysis of various components used in the proposed arrangement of solar vapor absorption refrigeration - air conditioning system has been carried out to improve the performance. It is seen that altering the geometrical property of the bubble pump, as well as heat input through a solar concentrating collector, use of hydrogen as a third fluid increases the rate of evaporation which in turn increases the cooling effect as well as COP of the cycle. At 54% concentration of LiBr and 4.5kW heat input, the COP of the proposed layout is found to be 0.61.

Keywords: Solar refrigeration, Vapour absorption, Air conditioning, Solar concentrator.

INTRODUCTION
The increasing atmospheric temperature is gradually challenging the sustainability of life due to global warming. Changing climatic conditions appear to be a consequence of the technological advances made at the cost of nature. This has resulted in excessive carbon emissions, ozone layer depletion, etc., which are disastrous for human beings. The increase in air conditioning requirements and refrigeration needs due to rising temperature are endangering the environment through CFC emissions from vapor compression refrigeration systems. The vapor absorption refrigeration cycle run on environment-friendly refrigerants can help mitigate the adversities created by the most vapor compression refrigeration cycle. The smaller energy requirements to run the vapor absorption refrigeration cycle for its operation make it further suitable in respect to the continually increasing energy requirements. The possibilities of utilizing renewable energy for getting refrigeration effects from less energy incentive cycle are explored by researchers worldwide. Solar energy availability in abundance motivates to attempt to have solar powered refrigeration cycle and using it for refrigeration/air conditioning purposes. In this context, the present work is undertaken to investigate the solar-powered vapor absorption refrigeration cycle that can be used for low-capacity air conditioning applications. Pioneering work carried out in this regard is detailed herein. Rahman et al.[1] performed an analysis in which he replaced the compressor by a generator, absorber and pump to produce 300 watt load at 23°C having cycle coefficient of performance 0.51. Sokhansefat et al.[2] performed parametric analysis of cycle having collector area 55m² and storage tank capacity 1m³ through which solar performance enhanced by 28%. Sharawi et al.[3] improved system performance by reducing the collector size and storage tank capacity of 5kW chiller. Solano-Olivares et al.[4] compared the Commercial Air Conditioning system with Solar Air conditioning which results in saving emission of 80% global warming potential as carbon footprint. Shelton et al.[5] developed a model which optimizes a Bubble Pump that runs the refrigeration cycle against gravity, having a Bubble pump tube diameter between 2 mm to 6mm to obtain maximum efficiency of the cycle. Bi Yuehong et al.[6] studied that collective use of a Parabolic trough collector (PTC) and 3-Phase accumulator with Solar Absorption Refrigeration improves...
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the efficiency of Parabolic Trough Collector i.e. 67.5%.[9] Cheng et al.[10] that the efficiency of the refrigeration cycle may get influenced by 2 or 3 times with change in solution concentration and absorbent variety and solar steam-based system having photo thermal material that localize the heat at the evaporation surface that helps in low loss of energy.[11]

Benhmidene et al.[12] studied the comparison between the homogeneous model of void fraction and vapor quality for pumping ratio 0.216 and void fraction 0.9, the optimum heat flux is between 5 to 10 kW/m². Zahor et al.[13] observed that the photovoltaic air conditioner’s economic performance totally depends on the self-consumption ratio and solar radiation amount. Aman et al.[14] compared that LiCl-H₂O having higher efficiencies as compared to LiBr-H₂O since LiCl-H₂O working pressure is high while LiBr-H₂O has crystallization constrain, which results in efficiencies of LiBr-H₂O and LiCl-H₂O as 0.46 and 0.56 respectively. Paurine et al.[15] studied the design and operation of thermo gravity pump which operates by low-grade energy i.e.temperature range of 75°C - 85°C to obtain COP of range 0.72 . Ezzine et al.[16] studied an experimental investigation on diffusion absorption having 2 fluids (Hydrocarbon, i.e., C₆H₁₄ / C₆H₁₆) as working fluid to obtain temperature range between -10°C to 10°C. Chaves et al.[17] studied 3 fluid refrigeration system i.e., ammonia-water-hydrogen having 14 distinct subparts for investigation, which shows a deviation of 2.5°C in a generator as well as 0.7°C in condenser for source power 80W. Anand et al.[18] studied the performance analysis of steam powered absorption refrigeration system. Aman et al.[19] studied the dimensional (geometrical) analysis of bubble pump to enhance the performance of bubble pump operated diffusion absorption refrigeration system, which results in 79% efficiency at start of slug flow regime. Also, the Bubble operates in turbulent conditions. Jemaa et al.[20] studied commercial Diffusion absorption for calculating overall heat transfer coefficient theoretically as well as experimentally, whose value resides between 0.2W/°C , so 35W-45W power is necessary for heating elements. Zohar et al.[21] Comparative analysis of with/without condensate cooling before evaporator entrance results in enhanced COP by 14–20% without condensate cooling at evaporator temperature 15°C. Bellos et al.[22] did study on efficiency of mechanical compression absorption cooling throughout the year based on solar system. Also did an economic as well as environmental impact study. Kilic et al.[23] studied the efficiency of LiBr-H₂O cooling system such that its efficiency is highest at higher generator temperature. Solano-Olivares et al.[24] studied the air conditioning system runs on fossil fuel also studied that solar equipped system reduces global warming by 80%. Soltani et al.[25] did experimental study on conversion of conventional air conditioner to solar air conditioner, also for absorption cooling - crystallization is major concern at high temperature range.

Based on the literature review, the solar powered vapour absorption cycle based refrigeration system calls for improving its effectiveness and devise it in useful form for being utilized for small capacity air conditioning needs of premises. Therefore, this study is carried out considering solar parabolic concentrator for running the vapour absorption cycle on Lithium Bromide – Water as working fluids for it.

Experimental Setup

The schematic of the studied arrangement for solar air conditioner after assessing various study of different technological solutions for low capacity cost effective solar air conditioners is given in Figure 1. This layout for a solar air conditioning system design is inclusive of the considerations for greenhouse gas emission reduction, ease of the availability of components and fabrication for making it cost effective.

LiBr – H₂O is used for getting the refrigeration effect in the evaporator section between states 3’ and 3. The room unit of air conditioner is installed between these states i.e. evaporator section. From state 3, the water should enter the absorber where LiBr will be entering into it. The concentrated LiBr-H₂O solution is sent to solution heat exchanger from where it goes to generator. Heat concentrated from solar collector falls on the generator from which water vapours enter the condenser at state 1 and condensate coming out at state 2 enters the expansion valve where the pressure is lowered and water enters evaporator at state 3’. The absorber operates at lower pressure and the pumping of a concentrated liquid mixture of LiBr and H₂O is realized from state 4 to solution heat exchanger and then to the generator at state 5. The weak solution leaves the generator at state 6 to return to the the solution heat exchanger from where it is expanded upto absorber pressure and enters at state 7.

The schematic layout of solar air conditioner has been used to arrive at the dimensional details of all components used in it for the refrigeration capacity needed for the 0.5 Ton air conditioner. The principal governing equations used for mathematical modeling based on energy considerations are as under.

Generator Modelling

Mass balance

\[ m_5 = m_1 + m_6 \]
Energy balance

\[ Q_{\text{gen}} = \dot{m}_1 h_1 + \dot{m}_5 h_5 - \dot{m}_3 h_3 \]

**Condenser Modelling**

Mass balance

\[ \dot{m}_1 = \dot{m}_2 \]

Energy balance –

\[ Q_{\text{cond}} = \dot{m}_1 h_1 - \dot{m}_2 h_2 \]

**Evaporator Modelling**

Mass balance

\[ \dot{m}_2 = \dot{m}_3 + \dot{m}_8 \]

Energy balance

\[ Q_{\text{evap}} = \dot{m}_3 h_3 - \dot{m}_2 h_2 - \dot{m}_8 h_8 \]

**Absorber Modelling**

Mass balance

\[ \dot{m}_8 + \dot{m}_4 = \dot{m}_7 + \dot{m}_3 \]

Energy balance

\[ Q_{\text{abs}} = \dot{m}_3 h_3 + \dot{m}_7 h_7 - \dot{m}_4 h_4 - \dot{m}_8 h_8 \]

**Cycle Performance**

In this setup, the only input energy is in form of solar energy through a bubble pump, so the coefficient of performance (COP),

\[ \text{COP} = \frac{\text{DESIRED EFFECT}}{\text{ENERGY INPUT}} = \frac{Q_{\text{evap}}}{Q_{\text{gen}}} \]

Based on the estimations carried out here, the brief description of the components of experimental set up created for solar air conditioning based on LiBr-H\(_2\)O vapour absorption refrigeration System is given ahead along with details of materials, and dimensions.

**Generator**

Generator is used for vaporization of refrigerant using heat available from solar collector. This is made up of steel and withstands the pressure at which refrigerant mixture is charged in it. The other details are given in Figure 2.

**Details** – Length : 0.4 m, Breadth : 0.4 m, Height : 0.4 m, Material used : Mild Steel

**Solar Collector**

Parabolic dish collector is used for capturing heat from the solar radiations. The generator is placed at the focus of the collector for carrying out the processes inside utilizing the heat available. The details of parabolic dish collector are as given in Figure 3.

**Details** – Diameter: 1.5 meter, Material used: Aluminium base with stainless steel taping

**Condenser**

Condenser has been got fabricated using copper tubes and suitable fins made up of aluminium. The condenser details are given along with Figure 4.

**Details** – Length:0.4 m, Breadth: 0.10 m, Height: 0.35 m, Material used: Copper(tubing), Aluminium (fins)

**Evaporator**

Evaporator is shown in Figure 5. It performs the function of creating cooling effect that cools the air being circulated in conditioned space. It has steel body and copper tubing.

**Details** – Length:1.2 m, Breadth: 0.65 m, Height: 0.4 m The material used: Steel (body), Copper (tubing), Aluminium (fins)

**Absorber**

Absorber facilitates the return of refrigerant from evaporator and mixing to get the refrigerant mixture suited for being sent to absorber. Figure 6 shows the details of absorber fabricated for this experimental study.
Complete Setup
The components that are required for running the refrigeration cycle and indoor room unit were assembled. The outdoor unit included the solar collector, generator, condenser, absorber, pump that are connected with suitable piping. The room unit included evaporator and fan inside it along with controls. Figures 7, 8, and 9 are showing the outdoor unit installed on the roof and Figure 10 demonstrates the indoor room unit.

Results and Discussion
The experimental set up assembled on roof top has been considered for study and the major outcome from the study is presented here. The input parameters considered for the results analysed are given in Table 1.

Variation of Cooling Effect (Qevap) with respect to different Heat Generation (Qgen) at 50% LiBr concentration
Figure 11 shows the effect on variation of cooling effect (Qevap) with respect to different Heat generation at 50% LiBr concentration in solution. The cooling effect (Qevap) keeps increasing as the amount of heat generation from solar collector to bubble pump increases. The cooling effect (Qevap) is directly dependent on mass flow rate of strong solution, which is dependent on volumetric flow rate of vapour refrigerant that depends upon the amount of heat generation from solar collector. As the heat generation increases, the strong solution’s mass flow rate increases, resulting in an increase in the cooling effect. At 2.5kW of heat generation, the cooling effect obtained is 1.54kW which is the minimum on the other hand, at 5kW of heat generation, the cooling effect obtained is 3.07kW which is the maximum in this range. The above graph has the values of heat generation taken in 0.5kW interval in range of 2.5 to 5kW to get following cooling effect 1.54 kW, 1.84 kW, 2.14 kW, 2.45 kW, 2.76 kW, 3.07 kW, respectively.
Variation of COP with respect to different Heat Generation (Qgen) at 50% LiBr concentration

Figure 12 shows the effect on variation of COP with respect to different heat generation at 50% LiBr concentration in solution. It is seen that on increasing the value of heat generation from solar collector, the COP of the setup is obtained as constant i.e., 0.61. The reason behind the constant nature of graph is that COP is ratio of Qevap to Qgen. Both values are directly dependent on mass flow rate of the strong solution (m_{ss}). So upon increasing the heat generation rate, the mass flow rate starts to increase, affecting both parameters equally in ratio. This results in obtaining the ratio constant. The heat generation values are taken in an interval of 0.5kW in range of 2.5kW to 5kW to get the COP 0.61, respectively.

Variation of mass flow rate of strong solution with respect to different heat generation value at 50% LiBr concentration

Figure 13 shows the variation of strong solution mass flow rate with different heat generation values. Since increasing heat generation, the mass flow rate of strong solution starts to increase because heat generation is responsible for the volumetric flow rate of vapour refrigerant.

Variation of mass flow rate of weak solution with respect to different heat generation value at 50% LiBr concentration

Figure 14 shows the variation of weak solution mass flow rate with different heat generation values. Since increasing heat generation, the mass flow rate of weak solution starts to increase because heat generation is responsible for the volumetric flow rate of vapour refrigerant.

Table 1: Input parameters

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar Collector Diameter</td>
<td>1.5 meter</td>
</tr>
<tr>
<td>2</td>
<td>Solar Intensity</td>
<td>4.5 kWh/m²/day</td>
</tr>
<tr>
<td>3</td>
<td>Effectiveness of Solar</td>
<td>90%</td>
</tr>
<tr>
<td>4</td>
<td>Collector</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Pressure of Generator</td>
<td>0.0567 bar</td>
</tr>
<tr>
<td>6</td>
<td>Pressure of Condenser</td>
<td>0.0567 bar</td>
</tr>
<tr>
<td>7</td>
<td>Pressure of Evaporator</td>
<td>0.0102 bar</td>
</tr>
<tr>
<td>8</td>
<td>LiBr Concentration</td>
<td>50%</td>
</tr>
<tr>
<td>9</td>
<td>Pressure Reducing Valve</td>
<td>90%</td>
</tr>
<tr>
<td>10</td>
<td>efficiency</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Temperature of Generator</td>
<td>70°C</td>
</tr>
<tr>
<td>12</td>
<td>Temperature of Condenser</td>
<td>35°C</td>
</tr>
<tr>
<td>13</td>
<td>Temperature of Evaporator</td>
<td>7°C</td>
</tr>
<tr>
<td>14</td>
<td>Temperature of Absorber</td>
<td>40°C</td>
</tr>
<tr>
<td>15</td>
<td>Temperature of Ambient</td>
<td>25°C</td>
</tr>
<tr>
<td>16</td>
<td>Specific volume of weak</td>
<td>0.00011m³</td>
</tr>
<tr>
<td></td>
<td>solution</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Specific volume of strong</td>
<td>0.0474m³</td>
</tr>
<tr>
<td></td>
<td>solution</td>
<td></td>
</tr>
</tbody>
</table>
Variation of mass flow rate of weak solution ($m_{sw}$) with respect to different heat generated at 50% LiBr concentration

Figure 14 shows the variation of weak solution mass flow rate with respect to different heat generation values. Upon increasing heat generation, the mass flow rate of the weak solution starts increasing and the weak solution flow rate droops down.

CONCLUSIONS

The results demonstrate that the cooling effect ($Q_{evap}$) starts to increase with an increase in heat generation ($Q_{gen}$). The COP of setup is independent of few parameters. On increasing the heat generation value, mass flow rate of the strong solution starts to increase while mass flow rate of the weak solution starts to decrease at a nominal rate. For enhanced efficiency of the whole system, it is also proposed to equip solar dish collectors with a tracking system for proper tracking of solar radiations. Pressure variation at the evaporator may give a different rate of evaporation, which affects the COP of the setup could be attempted. Also, the energy storage with the setup is a better idea for getting the refrigeration effect throughout the day.

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REFERENCES