Performance Evaluation of the Single-Stage Absorption Cooling System through Energy and Exergy Analysis

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Abstract. In this study, a single effect (H₂O-LiBr) water lithium bromide absorption cooling system is presented and evaluated by energy and exergy analysis. A mathematical thermodynamic model of the absorption cooling system has been found and derived from the basic principles of the first and second laws of the thermodynamics. The important parameters of performance are focused on the coefficient of performance COP and exergy efficiency. The performance was carried out over a range of operating conditions including the effect of generator, absorber and ambient temperatures. An energy and exergy investigation of separate system components were also obtained. The main obvious effect is detected for the situation of exergy efficiency for generator and absorber. The exergy efficiency increases with the rise of absorption temperature and a reverse effect is detected when the temperature of generator increases. The performance comparison of system components has been conducted in the present study. Exergy destruction of the generator was noticed to be 42% higher than exergy destruction in the absorber of 28%, due to the mixing of lithium bromide and water at high generator temperature of about 88°C. The COP of the absorption refrigeration system differs at the range (0.6 - 0.732) and maximum value was achieved at lowest temperature of absorber. The exergy analysis shows that the destroyed exergy distribution in the components of the system depends powerfully on the temperatures of system. The increasing in the generator temperature of higher than 88°C increases the COP of the current system, and with a additional increase in the generator temperature, the COP value stays constant. The obtained results lead to the documentation of factors that may affect the exergy efficiency of the (H₂O-LiBr) absorption system. It was found that the efficiency of the exergy of the system increased as a result of the increasing in the ambient temperature from (25°C to 45°C). The results show that the influence of system components condition on the total exergy loss is very significant.

Keywords. Energy analysis, Exergy analysis, Absorption, Refrigeration system.

1. Introduction
Many theoretical and experimental studies on the energy and exergy analysis of (H₂O-LiBr) absorption cooling systems are available in the literature. These studies used the principles of the second law of thermodynamics to enhance the system performance by reducing the irreversible losses in the system. Theoretical study is presented by Talbi and Agnew [1] who depended on the single stage absorption cooling systems type lithium bromide water (H₂O-LiBr). They found that an increase in the temperature of generator leads to an increase in COP of the refrigeration system, then the value of COP began to decrease gradually. Similar results were obtained by Sencan et al [2] who concluded that exergy losses were higher in the generator. The exergy analysis was also presented theoretically
by many other researchers. Kaushik and Arora [3] developed a theoretical study for a single stage (H₂O-LiBr) absorption refrigeration system. The purpose of this study was to archive improvement of the generator temperatures applied in order to improve the energy and exergy efficiencies and to find their effects on the exergy losses. The analysis was carried out on all cycle components. Also, they found that the rises in the temperature of generator leads to increases in COP then it began to decrease. Similar results were found by Sencan et al. They concluded that maximum exergy losses will be in the generator then the absorber. Kilic, et al [4] carried out a theoretical study on the performance of a single effect (H₂O-LiBr) absorption cooling system with cooling capacity of 10 tons and working by hot water as a thermal source. They developed a mathematical model that adopted the principle of energy conservation. The model equations were solved by energy equation solver (EES) program, then they determined a set of values for energy, exergy for all cycle components and the coefficient of performance. When the temperature of the hot water entering the generator was 88 °C and the temperature of the cooled water was 6.8 °C, the outcomes exposed that the highest exergy losses were in the cooling tower, absorber and generator respectively. Rivera et al [5] studied the absorption cooling cycle and focused on the exergy analysis of the cycle components. After their analysis, the highest irreversibility component was found in the absorber. To quantify the irreversible losses, Kaushik and Arora [6] compared the total entropy generation, which signifies the energy dissipation of the system by using the second law efficiency. The result showed that the largest exergy losses occur in the generator. It is clear from the results of most researchers that maximum exergy losses were in the generator. The main objective of the present research is to study the influence of operating temperatures variation on the exergy efficiency and COP, which are very important parameters to determine the exact location of weakness in order to enhance the performance of the cycle.

2. Components of absorption systems

The chief components of the single effect (H₂O-LiBr) absorption systems are the thermal source, pump, evaporator, absorber, generator, condenser and expansion device (valves including solution and refrigerant) as shown in Figure. 1. The principle of absorption cooling system is that the cooling fluid (or refrigerant fluid) is water, and the absorption material is Li-Br, which does not evaporate with water during the cycle operations. The nature of the solution in the generator will be concerted, but in the absorption vessel, it will be weakened. This is to reduce the heat energy required in the generator, and thus the energy production in the absorption vessel is reduced. Q̇\text{gen} is the heat input rate from the heat source, and Q̇\text{ab} and Q̇\text{cond} are the rates of heat rejection from absorber and condenser to the heat sinks correspondingly. Q̇\text{evap} represents the rate of heat withdrawn from the zone cooling load to the evaporator. As presented in Figure 1, the liquid solution (8) absorbs the refrigerant vapour coming from the evaporator (4). Then, this liquid solution is pumped across the heat exchanger (5-6). The refrigerant is evaporated from the solution by adding extra heat, then the refrigerant (water) returns to the condenser.

![Figure 1](image-url)  
**Figure 1.** Schematic diagram of cooling absorption system.
3. Mathematical model of cooling absorption system

The exergy of the flowing steady flow is calculated from the basic equations in order to study and analyse the performance of the system according to 1st and 2nd laws of thermodynamics (Hamza) [7], then the results were found by using MATLAB Program. In order to develop a mathematical model of the study, the following assumptions have been prepared for the absorption system.

1- Thermodynamic equilibrium at the outlet and inlet components.
2- The analysis is under steady state conditions.
3- The solution is saturated in the absorber and generator exit. Then in the evaporator and condenser exit, the refrigerant is saturated.
4- Dead state for exergy analysis is taken at 1 atmospheric pressure and 25 °C.
5- The weak solution is at absorber outlet.
6- The strong solution is at generator outlet.
7- Heat and pressure losses are negligible in each component.
8- Refrigeration cycle is characterized by a COP.
9- The difference between generator and absorber pressure is very small, so the pump work is neglected. [8].

The exergy content of a pure substance for a specific state [9]:

\[ E = (h - h_o) - T_o (s - s_o) + c^2/2 + g_z \]  \hspace{1cm} (1)

Where, \( h \) represents the enthalpy and \( h_o \) is the enthalpy at the dead state, \( T_o \) and \( s_o \) represent the temperature and entropy at the dead state correspondingly, when the changes in kinetic energy is neglected for the control volume, the exergy balance equation is given as [8]:

\[ \Delta E = \sum m_i e_i - \sum m_o e_o + \sum (1/T_k)Q_k \]  \hspace{1cm} (2)

When the heat removed from the absorber and condenser are not recycled, the third term in equation (2) is absent for absorber and condenser. Figure 1 specified the state of points in equation (2) The equations of exergy loss for all cycle component is as shown below:

The generator equations for energy and exergy balance can be written as in (4) and (5).

\[ Q_g = m_{1,w} h_{1,w} + m_{6,ss} h_{6,ss} - m_{7,ws} h_{7,ws} \]  \hspace{1cm} (3)

\[ \Delta E_g = m_{6,ss} h_{6,ss} - m_{1,w} h_{1,w} - m_{7,ws} h_{7,ws} + Q_g (1-T_0/T_g) \]  \hspace{1cm} (4)

Where, \((m_{1,w})\) is the working fluid (water) mass flow rate, \((m_{6,ss})\) mass flow rate (water) at saturation condition, \(h_{1,w}\) enthalpy of water and \(h_{7,ws}\) is the enthalpy of water at saturation condition. The condenser equations for energy and exergy balance can be able to write as in (5) and (6).

\[ Q_c = m_{1,w} h_{1,w} - m_{2,w} h_{2,w} \]  \hspace{1cm} (5)

\[ \Delta E_c = m_{1,w} e_{1,w} - m_{2,w} e_{2,w} \]  \hspace{1cm} (6)

The expansion valve equations for energy balance can be able to write as in (7) and (8). Energy balance of expansion device be able to write as in (7) and (8).

\[ h_{2,w} = h_{3,w} \]  \hspace{1cm} (7)

\[ h_{9,ss} = h_{10,ss} \]  \hspace{1cm} (8)
Energy and exergy balance of evaporator [10] described as in (9) and (10).

\[ Q_e = m_{4,w} \cdot h_{4,w} - m_{3,w} \cdot h_{3,w} \]  

(9)

\[ \Delta E_e = m_{3,w} \cdot e_{3,w} - m_{4,w} \cdot e_{4,w} - Q_e \left( 1 - \frac{T_o}{T_e} \right) \]  

(10)

Energy and exergy balance of pump described as in (11) and (12)

\[ w_p = m_{6,ws} \cdot h_{6,ws} - m_{5,ws} \cdot h_{5,ws} \]  

(11)

\[ \Delta E_p = m_{5,ws} \cdot h_{5,ws} - m_{6,ws} \cdot h_{6,ws} + w_p \]  

(12)

Energy and exergy balance of absorber described as in (13) and (14)

\[ Q_{abs} = m_{4,w} \cdot h_{4,w} + m_{10,ss} \cdot h_{10,ss} - m_{5,ws} \cdot h_{5,ws} \]  

(13)

\[ \Delta E_{abs} = m_{4,w} \cdot e_{4,w} + m_{10,ss} \cdot e_{10,ss} - m_{5,ws} \cdot e_{5,ws} \]  

(14)

Total energy balance is described as in (15) [11]:

\[ Q_g + Q_e = Q_c + Q_{abs} \]  

(15)

The overall COP cooling of the system is obtained by (16):

\[ COP = \frac{Q_e}{Q_g} \]  

(16)

Exegetics Coefficient of Performance (system COP) [12]:

\[ COP = \frac{Q_e}{Q_g} = \frac{m_{1,sw} \cdot (h_{4,sw} - h_{3,sw})}{m_{1,sw} \cdot h_{1,sw} + m_{6,ss} \cdot h_{6,ss} - m_{7,ws} \cdot h_{7,ws}} \]  

(17)

Exegetics efficiency (second - law efficiency):

\[ \eta_{II} = 1 - \frac{(1 - \frac{T_o}{T_e}) \cdot Q_e}{(1 - \frac{T_o}{T_g}) \cdot Q_g} \]  

(18)

4. Results and discussion

An alternative view of system performance predicted by the second law analysis gave us an understanding that the first law analysis could not give clear information about how actual losses at different components are dependent. This information gives the designer the ability to find where the design must be enhanced to reach the optimum performance. In this work, the exergy analysis is used to study and evaluation of performance of single effect of (H2O-LiBr) absorption cooling system, when many of parameters are diverse. The values of COP are calculated from the thermodynamics properties of the refrigeration fluid (water) at different operational conditions by using MATLAB program. Figure 2. represents the changing in temperature of the generator with the COP at various absorber temperatures of the absorption refrigeration system. The effect of the mass flow rate of the refrigeration fluid (water) was not studied because it was abbreviated as it appears in the numerator and denominator of the COP equation. The system COP varies at a range (0.6 - 0.732), and maximum
value was found at lowest absorber temperature. The increasing in the temperature of generator up to 88°C increased the COP of the current work. The additional rise in the generator temperature leads the COP value to decrease by a very small difference and seems nearly constant because the small amount of heat that is lost with the increase of generator temperatures. Figure 3 shows the change in the temperature of the generator with various approaches temperature difference for the condenser. The COP of the absorption refrigeration cycle varied between (0.6 - 0.7104), while the maximum value was found at lesser approach temperature difference for the condenser about 5°C. The rise in the temperature of generator to 88°C increases the value of COP for the current work, and with an additional rise in the temperature of generator the COP value decreases by a very small difference and appears nearly constant and this is similar to the results of the researchers [2,3]. This small difference in COP values results from the small amount of heat loses with the increase of generator temperatures to more than 88°C. Figure 4. Illustrates the relation between the rational efficiency and system COP at various generator temperatures. The rise in the temperature of the generator leads to rise in the value of COP increases yet remains almost constant with an additional increase in the temperature of generator. The rational efficiency firstly increases, then it started to decrease caused by the increased of irreversibility in the generator. Lastly, in the single effect (H2O-LiBr) the optimum temperature for the generator is 88°C, when operated by water as a refrigeration fluid as shown in the above figure. Figure 5 shows the exergy destruction of generator at various generator temperatures with various ambient temperatures. When the temperature of the generator increases, the value of exergy destruction in the generator increases also and it remains almost constant with a further increase in the temperature of generator. The value of exergy destruction of the generator increases due to decreasing in ambient temperature due to increased irreversibility in the generator. Figure 6 illustrates the absorber exergy destruction at various generator temperatures with various ambient temperatures. The rise in the temperature of generator leads to reduction in the exergy destruction of the absorber, but remains almost constant with a further increase in the temperature of generator. Exergy destruction of the absorber increases as the ambient temperature increases, since this rise in ambient temperature reasons an additional in irreversibility. This phenomenon occurs clearly at high difference in temperature, which leads to more irreversibility due to the increase in entropy generation with the rise of ambient temperature.

![Figure 2](image_url)  
**Figure 2.** Temperature of generator variation with COP at different absorber temperature.
Figure 3. Temperature of generator variation with COP at different condenser temperature.

Figure 4. Temperature of generator variation with COP and rational efficiency.

Figure 5. Exergy destruction of generator variation with generator temperature at various ambient temperature.
5. Conclusions
The results indicate that an increase in the generator temperature involves an increase in COP and then decrease while the total exergy losses (high irreversibility) of the system increases. The COP of the (H₂O-LiBr) absorption refrigeration system varies at a range (0.6 - 0.732), and maximum value is found at minor temperature of absorber.
In cooling absorption system, the maximum destruction is obtained in the generator 42% and in the absorber 27%, which is caused by from the mixing process at the maximum difference of temperature. In order enhance the COP of the absorption cooling system, the generator and the absorber of the system should be taken into consideration when designing, then these two components display maximum exergy destruction with their heat transference.
The COP of the system is more responsive to change in the generator and evaporator operating conditions or any additional changes in the conditions of the cycle that affects the generator and evaporator, while the irreversibility reflects the effect of all the system components.

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Figure 6. Exergy destruction of absorber variation with generator temperature at various ambient temperature.
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Acknowledgements
This research was funded by a grant from the university of Tikrit / Iraq (Free Grant)