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Comparative analysis of the performance and exergy efficiency of absorption cooling system for different working fluids

Mehmet ALTINKAYNAK*[1], Arzu ŞENCAN ŞAHİN[1]

[1]Isparta University of Applied Sciences, Technology Faculty, Mechanical Engineering Department 32260, Isparta, TURKEY

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Abstract: In this study, the first and second laws of thermodynamics have been employed to evaluate energy and exergetic efficiency of the single effect absorption cooling system. $LiBrH_2O$, LiSSC and $LiCl-H_2O$ were used as working fluid in the absorption cooling system. The energy, exergetic efficiency and circulation ratio values at various operating conditions for different working fluids were investigated. The results showed the absorption cooling system with $LiCl-H_2O$ solution has the highest COP and exergetic efficiency value for different operating temperatures. In addition, the irreversibility values of each system component were calculated. The results showed that maximum irreversibility was occurred in the generator and absorber. EES program was used in all analyzes. Obtained results from this study can be used for optimization of absorption cooling system and obtaining optimum operating conditions.

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Farklı çalışma sıvıları için absorpsiyonlu soğutma sisteminin performansı ve ekserji verimliliğinin karşılaştırmalı analizi

Anahtar Kelimeler
Absorpsiyonlu soğutma,
Enerji Analizi
Ekserji Analizi
Tersinmezlik
Çalışma Akışkanları

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Öz: Bu çalışmada, termodinamiğin birinci ve ikinci kanunları, tek etkili absorpsiyonlu soğutma sisteminin enerji ve ekzerjik verimliliğini değerlendirmek için kullanılmıştır. Absorpsiyonlu soğutma sisteminde çalışma sıvısı olarak $LiBrH_2O$, LiSSC ve $LiCl-H_2O$ kullanılmıştır. Farklı çalışma akışkanları için çeşitli çalışma koşullarında enerji, ekzerjetik verimlilik ve sirkülasyon oranı değerleri incelenmiştir. Sonuçlar, $LiCl-H_2O$ solüsyonlu absorpsiyonlu soğutma sisteminin farklı çalışma sıcaklıkları için en yüksek COP ve ekzerjik verimlilik değerine sahip olduğunu gösterdi. Ayrıca her bir sistem bileşeninin tersinmezlik değerleri hesaplanmıştır. Sonuçlar, jeneratörde ve soğurucuda maksimum tersinmezliğin oluştuğunu gösterdi. Tüm analizlerde EES programı kullanılmıştır. Bu çalışmadan elde edilen sonuçlar absorpsiyonlu soğutma sisteminin optimizasyonu ve optimum çalışma koşullarının elde edilmesi için kullanılabilir.

* İlgili yazar/Corresponding author: mehmetaltinkaynak@isparta.edu.tr

1. Introduction

The absorption cooling systems are becoming more attractive nowadays, especially because of their environmental friendliness and using of renewable energy. The absorption cooling systems have been studied from both theoretical and experimental points of view. Some studies in literature related to first and second law analysis of absorption cooling systems were reported in Table 1.

Table 1. Some studies related to absorption cooling systems in literature

Working fluids	Topic	Authors
LiBr-water	Energy and exergy	Kaushik and Arora [1,2]
LiBr-water	Energy and exergy	Kaynakli et al. [3]
Ammonia–water	Energy and exergy	Aman et al. [4]
LiBr-H_2O and NH3-H_2O	Exergy analysis	Khaliq and Kumar [5]
Ammonia–water	GAX, exergy	Eisavi et al. [6]
LiBr-water	Exergy analysis	Maryami and Dehghan [7]
LiBr-water	Energy and exergy	Razmi et al. [8]
LiBr-water	Exergy efficiency	Garcia-Hernando et al. [9]
LiCl-water	Exergy analysis	Gogoi and Konwar [10]
LiBr-water	Exergy analysis	Joybari andHaghighat [11]
LiBr-water	Triple effect absorption	Agarwal et al. [12]
LiBr-water	Energy, exergy, ANN	Singh and Verma [13]
LiBr-water	Optimization, Exergy	Mahalle et al. [14]
LiBr-water	Performance Optimization, Exergy	Canbolat et al. [15]
LiBr-water	Thermodynamic performance	Bagheri et al. [16]
LiBr-water	Exergetic Analysis	Parvez et al. [17]
LiBr-water	Cost Optimization	Colorado-Garrido [18]
LiBr-water	Energy and exergy	Mussati et al. [19]
EMISE–Water	Energy and exergy	Takalkar et al. [20]
LiBr-water	Energy and exergy	Panahı and Bozorgan [21]
LiBr-water	Energy and exergy	Modi et al. [22]

As seen above, numereos study has been conducted on absorption cooling. The energy-exergy, price optimization and system performance optimization of the refrigerants used in these studies (LiBr-water, Ammonia-water, LiBr-H_2O and NH3-H_2O, LiCl-water, EMISE-Water) were performed.

Available literature, there is no information about thermodynamic performace of refrigerant of LiBrSCC on absorption cooling systems. In this study, as unlike from literature, comparative analysis of the performance and exergy efficiency of the absorption cooling system for different working fluids (LiCl, LiBr, LiBrSSC) were carried out. The irreversibility values for all system components of system were obtained.

2. System Description

Absorption cooling system is presented in Fig. 1. The system consists of absorber, solution pump, generator, evaporator, condenser, expansion valve and solution heat exchanger. As given Fig. 1, absorber output (1-2), the solution is abundant in refrigerant and solution pump drives the liquid from solution heat exchanger to the generator (2-3). LiCl, LiBr, LiBrSSC solutions were used as adsorber and water as cooling fluid water in the system. The temperature of solution rises in the heat exchanger. Thermal energy adds to generator and refrigerant quit from the solution. The refrigerant vapour (7-8) streams to the condenser. Refrigerant that condensed streams from expansion valve to evaporator. Heat is drawn from the ambient and the refrigerant evaporates (9-10). Refrigerant that evaporates arrives to absorber (10-1). The solution at generator (7-4) outlet comes to the heat exchanger and cooled. The vapour refrigerant which came from evaporator is absorbed whereby liquid solution (6) [23].

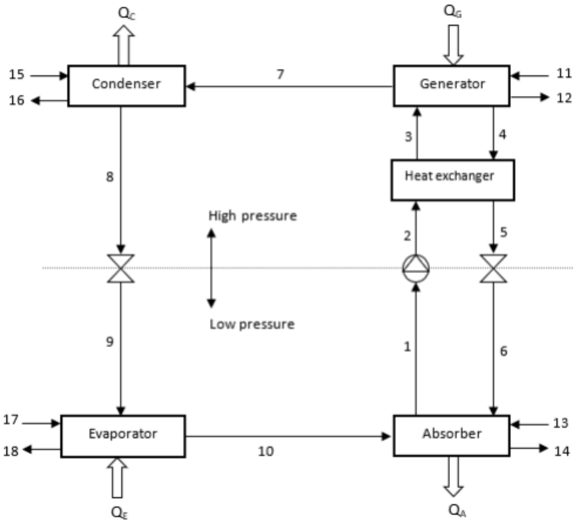

Figure. 1. Schematic diagram of absorption refrigeration system

First and second law of thermodynamics is applied to each component of the absorption system. Each component of system can be implemented as control volume with heat transfer, inlet and outlet association with work. In the system, mass preservation involves the mass balance of each component of the solution. Mass conservation equations for a steady state and a steady flow systems is [24].

$$\sum \dot{m}_i - \sum \dot{m}_o = 0 \tag{1}$$

$$\sum(\dot{m}x)_i - \sum(\dot{m}x)_o = 0 \tag{2}$$

Subscripts i and o shows mass inlet and mass outlet respectively and x is mass density of LiBr in the solution.

When kinetic and potential energy changes are negligible, the first law or energy balance relation for steady flow system:

$$\dot{Q} - \dot{W} = \sum(\dot{m}h)_0 - \sum(\dot{m}h)_i \tag{3}$$

An overall energy balance of the system requires that the sum of the generator, evaporator, condenser and absorber heat transfer must be zero.

Assuming that the absorption system model is steady and that pump operation and environmental heat losses are neglected,

The energy balance can be expressed as follows:

$$\dot{Q}_C + \dot{Q}_A = \dot{Q}_G + \dot{Q}_E \tag{4}$$

The ratio of solution mass flow rate through the pump to the mass flow rate refrigerant defined as the flow ratio (FR) and written as follows [23]:

$$FR = \frac{\dot{m}_3}{\dot{m}_7} \tag{5}$$

The coefficient of performance (COP) for cooling of the system are obtained as:

$$COP = \frac{\dot{Q}_E}{\dot{Q}_G} \tag{6}$$

The second law analysis is a used in determining the theoretical limits for the performance of commonly used engineering systems (refrigeration systems, heat pumps et al.). The second law defines perfection for thermodynamic process. It can be used to quantify the level of perfection of a process, and point the direction to eliminate imperfections effectively [25].

The second law of thermodynamics analysis applied to a system describes all loses both in the various components of the system and in the whole system. With the help of this analysis the magnitude of these loses or irreversibilities and their order of importance can be understood. With the use of irreversibility, which is a measure of process imperfection, the optimum operating conditions can easily be determined. The advantage of the second law analysis based on thermoeconomic optimization is that the different elements of the system could be optimized independently. It is possible to say that the second law analysis can indicate the possibilities of thermodynamic improvement of the process under consideration [26].

The entropy balance relation for a general steady-flow process can be expressed as following [25]:

$$\dot{S}_{gen} = \sum \dot{m}_o s_o - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k} \quad (7)$$

Irreversibility can be defined as:

$$I = T_0 \dot{S}_{gen} \quad (8)$$

The energy and entropy balance equations of the various components of an absorption system are given Table 2.

The exergy efficiency can be written as [22]:

$$\eta_{II} = \frac{\dot{Q}_E\left(\frac{T_0}{T_E}-1\right)}{\dot{Q}_G\left(\frac{T_0}{T_G}-1\right)} \quad (9)$$

Table 2. The energy and entropy balance equations of absorption system components

Components	Energy Balance	Entropy Balance
Solution Pump	$\dot{m}_1 h_1 + \dot{W}_{sp} = \dot{m}_2 h_2$	$I_{sp} = \dot{m}_1 T_0 (s_2 - s_1)$
Solution Heat Exchanger	$\dot{m}_2 h_2 + \dot{m}_4 h_4 = \dot{m}_3 h_3 + \dot{m}_5 h_5$	$I_{SHE} = T_0[\dot{m}_3(s_3 - s_2) - \dot{m}_5(s_4 - s_3)]$
Solution Expansion Valve	$h_5 = h_6$	$I_{SEV} = \dot{m}_8 T_0 (s_9 - s_8)$
Absorber	$\dot{Q}_A = \dot{m}_6 h_6 + \dot{m}_{10} h_{10} - \dot{m}_1 h_1$	$I_A = T_0[\dot{m}_1 s_1 - \dot{m}_6 s_6 - \dot{m}_{10} s_{10} - \dot{m}_{13}(s_{13} - s_{14})]$
Generator	$\dot{Q}_G = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3$	$I_A = T_0[\dot{m}_4 s_4 - \dot{m}_3 s_3 - \dot{m}_{11}(s_{11} - s_{14}) + \dot{m}_7 s_7]$
Condenser	$\dot{Q}_C = \dot{m}_7 h_7 + \dot{m}_8 h_8$	$I_C = T_0[\dot{m}_7(s_7 - s_8) - \dot{m}_{15}(s_{15} - s_{16})]$
Refrigerant Expansion Valve	$h_8 = h_9$	$I_{REV} = \dot{m}_5 T_0 (s_6 - s_5)$
Evaporator	$\dot{Q}_E = \dot{m}_{10} h_{10} + \dot{m}_9 h_9$	$I_C = T_0[\dot{m}_9(s_{10} - s_9) - \dot{m}_{17}(s_{17} - s_{18})]$

3. Results and Discussion

The graph showing the changes of COP values according to generator temperatures for the absorption system using different fluids is given in Fig. 2. As seen from the graph, as the generator temperature increases, the value of the COP increases for three working fluids. When the generator temperature reaches 65ºC for the fluids, it is seen that the COP values start to stabilize. Among the working fluids, the highest COP of the system was obtained for LiCl-H_2O fluid.

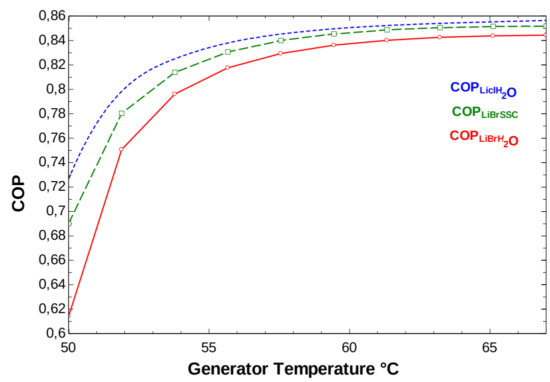

Figure. 2. Role of generator temperature on COP values

For the three working fluids, the variation the COP with the absorber temperature is presented in Fig.3. As the absorber temperature for all fluids increases the COP decreases. Among the working fluids, the highest COP of the system was obtained for LiCl-H_2O fluid.

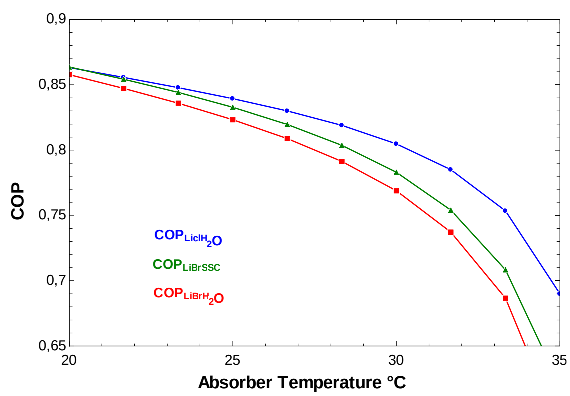

Figure. 3. Role of absorber temperature on COP values

In Fig. 4, the variation of COP with the condenser temperature for three different fluids used in the absorption system is shown. While the condenser temperature increases, the COP decreases. LiCl-H_2O fluid pair has the highest COP value in the system depending on the condenser temperature value. The variation the COP with the evaporator temperature is seen in Fig.5. While the evaporator temperature increases, the COP increases. It was observed that the system working with LiBrSSC working fluid at the evaporator temperature above 6.5 °C had higher COP values.

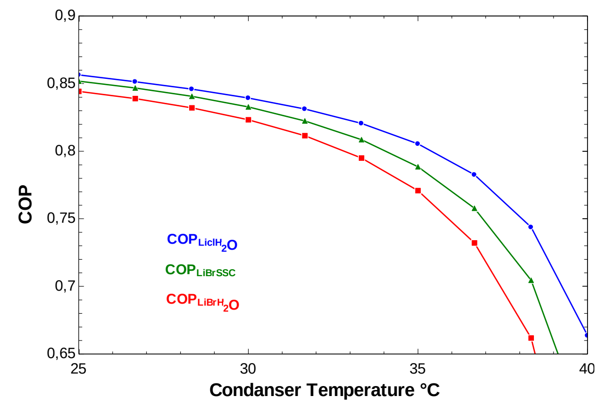

Figure. 4. Role of condenser temperature on COP values

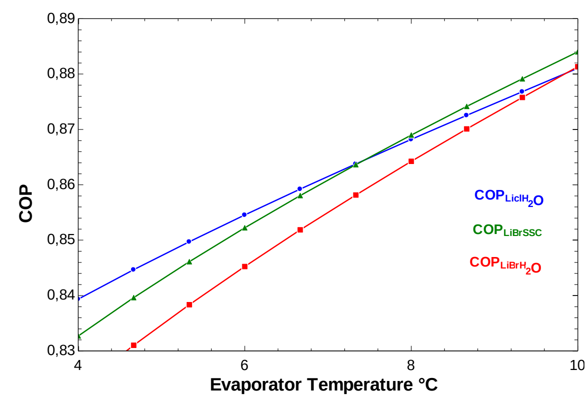

Figure. 5. Role of evaporator temperature on COP values

In Fig. 6, the variation of the exergy efficiency of the absorption cooling system with absorber temperature is presented. As the absorber temperature increases, the exergy efficiency decreases. In addition, the LiBr-H_2O fluid couple has lower exergy efficiency than the other working fluids.

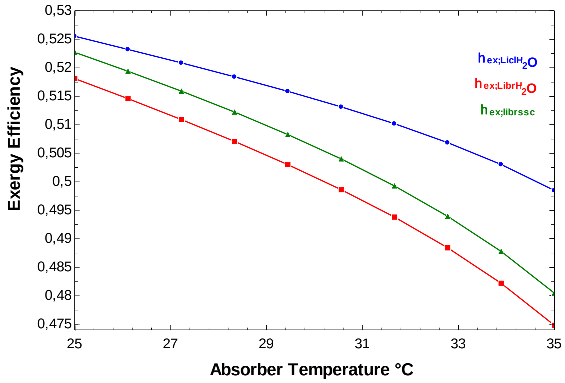

Figure.6. Role of absorber temperature on exergy efficiency

The relationship between the exergy efficiency and generator temperature for the fluid pairs used in the system is given in Fig. 7. As the generator temperature increases, the exergy efficiency decreases. For LiBr-H_2O and LiSSC fluid couples, the exergy efficiency of the absorption cooling system with the generator temperature is affected at the same rate.

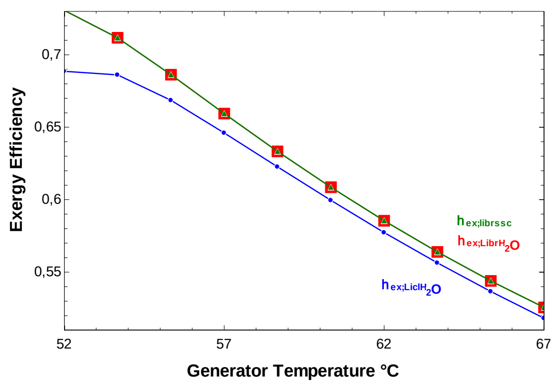

Figure. 7. Role of generator temperature on exergy efficiency

The relationship between the condenser temperature and the exergy efficiency of the system is shown in Fig. 8. As the condenser temperature increases, the exergy efficiency decreases. Exergy efficiencies are from highest to lowest, respectively, LiBr-H_2O, LiBrSSC and finally LiCl-H_2O fluid pairs. The exergy efficiency of the system depending on the evaporator temperature is shown in Fig. 9. It was determined that there was an inverse ratio between the evaporator temperature and the exergy efficiency of the system. In all three fluid pairs, as the evaporator temperature increases, the exergy efficiency decreases.

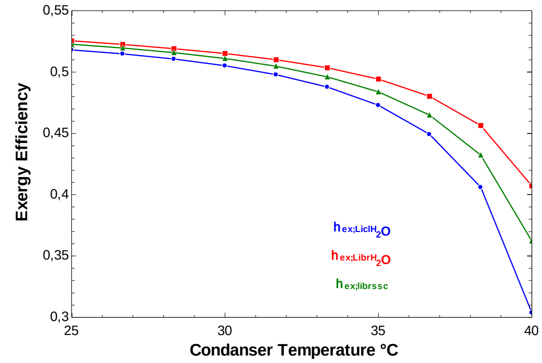

Figure. 8. Role of condanser temperature on exergy efficiency

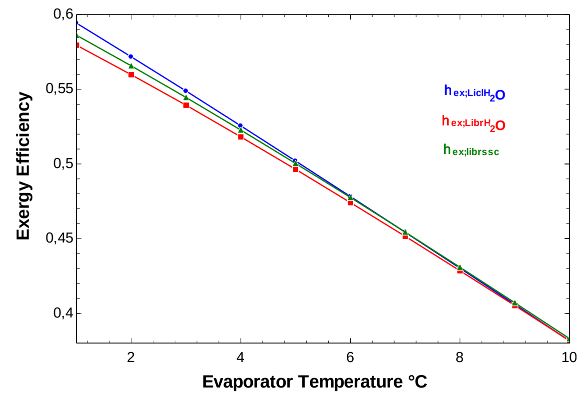

Figure. 9. Role of evaporator temperature on exergy efficiency

Fig.10 and Fig.11 show the variation between the flow ratio (FR) and evaporator and generator temperatures for different fluid pairs. Flow ratio values are seen decrease with increasing temperature. In Fig.12, effect of condenser temperature on flow ratio is seen. As the condenser temperature increases, the flow ratio values increase.

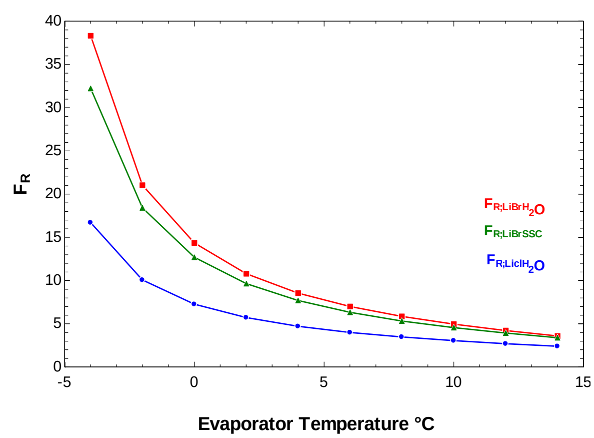

Figure. 10. Effect of evaporator temperature on flow rate

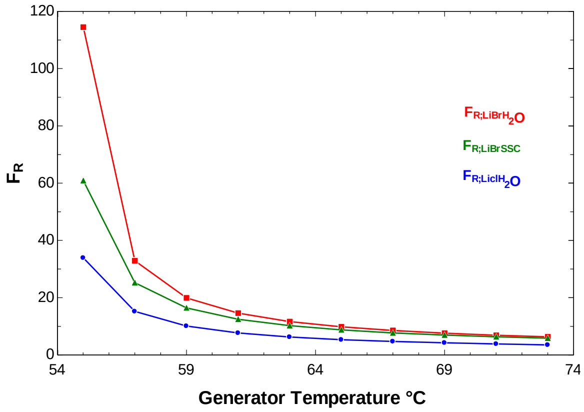

Figure. 11. Effect of generator temperature on flow rate

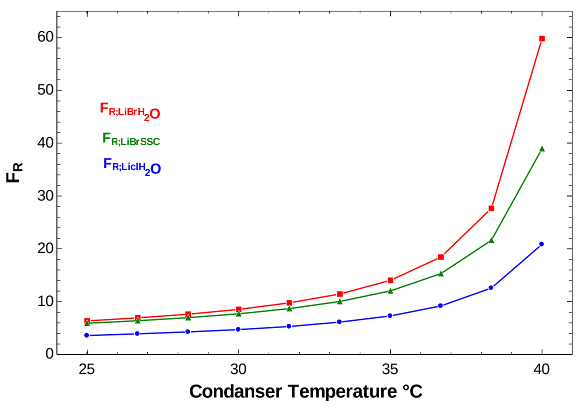

Fig. 12. Effect of condenser temperature on flow rate

Fig. 13. shows the relative irreversibility (exergy destruction) of each component of the absorption cooling system. For all fluid pairs, it is seen that the absorber has the highest irreversibility. The next highest irreversibility has occured in the generator. Among the fluid pairs, the highest irreversibility in the system belongs to the system operating with the LiBrSSC fluid pair. Since irreversibility in the pump and expansion valves are small then their effect on the total irreversibility could be neglected.

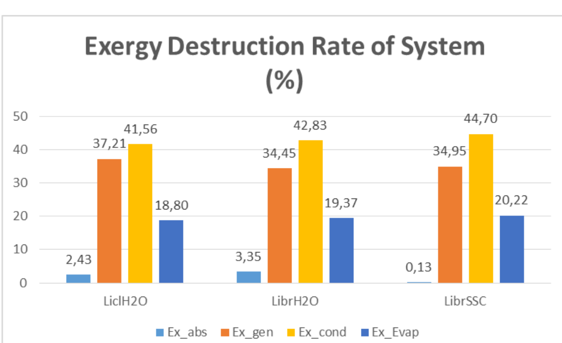

Figure. 13. Role of exergy destruction rate of system (%)

4. Conclusion

In this work, comparative analysis of the performance and irreversibility of the single effect absorption cooling system for LiBr-H_2O, LiSSC and LiCl-H_2O working fluids was performed. The performance parameters computed are coefficient of performance (COP), irreversibility and exergetic efficiency. The results show that COP of the single effect system lies in range of 0.6–0.88. The flow ratio (FR) has a strong effect on the system performance. The relationship between the FR with evaporator, generator and condenser temperatures was investigated. It was shown that the obtained results were found in parallel to the system component temperature and the COP changing. Exergy efficiency of the single effect system lies in range of 0.3–0.73. Irreversibility is highest in the generator and absorber when compared to other system components. Obtained results from this study can be used for optimization of absorption cooling system and obtaining optimum operating conditions.

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Nomenclature

h	: enthalpy (kJ/kg)
I	: rate of irreversibility (kW)
$\dot{m}$	: mass flow rate (kg/s)
Q	: heat load (kW)
s	: specific entropy (kJ/kgK)
T	: temperature (K)
W	: work (kW)
x	: mass concentration of LiBr in the solution (%)

Subscripts

A	: absorber
C	: condenser
E	: evaporator
EV	: expansion valve
G	: generator
i	: inlet
SHE	: solution heat pump
SP	: solution pump
T	: total
W	: work
o	: out
0	: ambient