



**Research Paper / Makale**

**Thermodynamic and Exergy Analysis of an Absorption Cooling System for Different Refrigerants**

**Dilek Nur ÖZEN<sup>1\*</sup>, Kemal Çağrı YAĞCIOĞLU<sup>1</sup>**

<sup>a</sup>Necmettin Erbakan University, Faculty of Engineering and Architecture, Department of Mechanical Engineering, 42140 Konya/TURKEY  
dnozen@erbakan.edu.tr

**Received/Geliş:** 20.07.2019

**Accepted/Kabul:** 14.10.2019

**Abstract:** In absorption cooling systems, the compression of the working fluid is not made by the compressor but by a system consisting of absorbers, pumps and generators. The fact that the compressor is not used for compression reduces the power required for this process. In this case, absorption cooling systems are very useful when used with renewable energy sources. In this study, thermodynamic and exergy analysis of the system was performed to see the effects of different refrigerant solutions on the performance of an absorption cooling system. In the absorption cooling system for Lithium bromide-Water (LiBr-H<sub>2</sub>O), ammonia-water (NH<sub>3</sub>-H<sub>2</sub>O), ammonia-lithium nitrate (NH<sub>3</sub>-LiNO<sub>3</sub>) and ammonia-sodium thiocyanate (NH<sub>3</sub>-NaSCN) fluid couples, the Coefficient of Performance (COP) and Exergy Efficiency (%) of the system were examined for each fluid pair by analyzing at different generator, evaporator and absorber temperatures. Analysis results indicate that the LiBr-H<sub>2</sub>O solution pair showed better performance (higher COP and exergy efficiency) than the other solution pairs (NH<sub>3</sub>-H<sub>2</sub>O, NH<sub>3</sub>-LiNO<sub>3</sub>, NH<sub>3</sub>-NaSCN).

**Keywords:** Exergy; ammonia/NH<sub>3</sub>; LiBr/H<sub>2</sub>O; ammonia/NaSCN; absorption refrigeration. system.

**Farklı Soğutucu Akışkanlar için Bir Absorbsiyonlu Soğutma Sisteminin Termodinamik ve Ekserji Analizi**

**Öz:** Absorpsiyonlu soğutma sistemlerinde çalışma akışkanının sıkıştırma işlemi kompresörle değil absorber, pompa ve jeneratörden oluşan bir sistemle yapılmaktadır. Sıkıştırma işlemi için kompresör kullanılmaması bu işlem için ihtiyaç duyulan gücü azaltmaktadır. Bu durumda absorpsiyonlu soğutma sistemleri yenilenebilir enerji kaynakları ile kullanıldığında oldukça kullanışlı olmaktadır. Bu çalışmada farklı soğutucu akışkan çözeltilerinin bir absorpsiyonlu soğutma sisteminin performansı üzerindeki etkilerini görebilmek için sistemin termodinamik ve ekserji analizi yapılmıştır. Lityum bromür-Su (LiBr-H<sub>2</sub>O), amonyak-su (NH<sub>3</sub>-H<sub>2</sub>O), amonyak-lityum nitrat (NH<sub>3</sub>-LiNO<sub>3</sub>) ve amonyak-sodyum tiyosiyanat (NH<sub>3</sub>-NaSCN) akışkan çiftleri için absorpsiyonlu soğutma sisteminde farklı jeneratör, buharlaştırıcı ve absorber sıcaklıklarında analiz yapılarak sistemin Soğutma Tesir Katsayısı (STK) ve Ekserji Verimleri (%) her bir akışkan çifti için incelenmiştir. Analiz sonuçları LiBr-H<sub>2</sub>O çözelti çiftinin diğer akışkan çiftlerine (NH<sub>3</sub>-H<sub>2</sub>O, NH<sub>3</sub>-LiNO<sub>3</sub>, NH<sub>3</sub>-NaSCN) göre daha iyi bir performansa sahip olduğunu göstermiştir.

**Anahtar kelimeler:** Ekserji; NH<sub>3</sub>; LiBr/H<sub>2</sub>O; NH<sub>3</sub>/NaSCN; absorpsiyonlu soğutma sistemi.

**1. Introduction**

With growing technology and rapid population growth in the world, energy needs are increasing. On the other hand, there is an energy problem in our country and in the world. It is envisaged that classical energy types cannot meet this ever-increasing need for energy. The prices of oil and existing energy are increasing due to the limited energy resources and the diminishing use of these resources' day by day. The search for alternative energy sources brings renewable energy sources to

*How to cite this article*

Özen D. N., Yağcıoğlu K., "Thermodynamic and Exergy Analysis of an Absorption Cooling System for Different Refrigerants", El-Cezeri Journal of Science and Engineering, 2020, 7 (1); 93-103.

*Bu makaleye atıf yapmak için*

Özen D. N., Yağcıoğlu K., "Farklı Soğutucu Akışkanlar için Bir Absorbsiyonlu Soğutma Sisteminin Termodinamik ve Ekserji Analizi", El-Cezeri Fen ve Mühendislik Dergisi 2020, 7 (1); 93-103.

the forefront. Absorption refrigeration systems enable the utilization of renewable energy sources. Despite the large amount of heat energy required for absorption cooling systems, the mechanical energy required to operate the cycle is very low. For this reason, the heat energy required in such cooling systems will reduce the operating costs of the system of supplying energy from cheap energy sources such as geothermal or solar energy. In addition, CFC-containing (chlorofluorocarbon) solutions are not used in absorption cooling systems, so these systems are extremely environmentally friendly cooling systems.

In recent years, interest has been focused on the improvement of absorption cooling systems and scientific studies. Kaita [1] developed equations that can calculate the vapor pressure, enthalpy and entropy of LiBr solutions at such high temperatures. The equations developed are valid at concentrations of 40-65% by weight and also at temperatures of 40-210°C. Florides et al. [2] described the heat and mass transfer equations to be used in the design and construction of a single-effect absorption cooling cycle using H<sub>2</sub>O-LiBr solution pairs and derived new equations using these equations.

Abdulateef et al. [3] examined new working fluids for the solar absorption cooling system. They developed a computer simulation model to estimate the performance of a solar absorption cooling system using different working fluids.

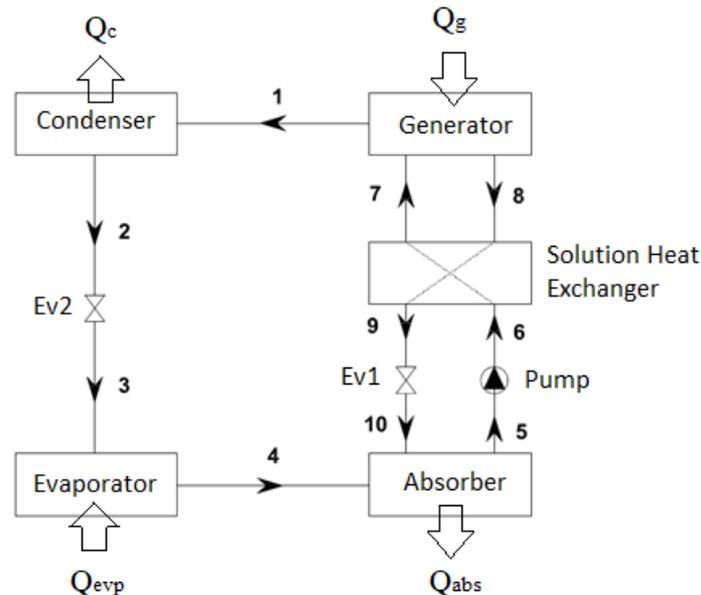
Crepinsek et al. [4] investigated the comparison of the performance of absorption cooling cycles. In this paper, the performances of ammonia water and possible alternative cycles are compared in terms of coefficient of performance (COP) and circulation rate (f). The highest COP and lowest f were found as a function of the generator, condenser, absorber and evaporation temperature. Manu et al. [5] made the theoretical shock absorber model for the LiBr-H<sub>2</sub>O pair of miniature absorption cooling systems. Patel et al. [6] examined the energetic analysis of the single-stage lithium bromide water absorption cooling system. They showed that the heat load on the generator and the absorber increased with the rise of the generator and condenser outlet temperature and decreased when both the evaporator and generator outlet temperature increased simultaneously.

Farshi et al. [7] conducted an energy and exergy analysis of ammonia / salt absorption cooling systems. They examined the effect of various working parameters on performance and the possibility of crystallization in these cycles. This study showed that ammonia / LiNO<sub>3</sub> cycles had better performance for low generator temperatures. Bouaziz and Lounissi [8] presented an energy and exergy review of a new dual-effect hybrid absorption cooling system for solar cooling. Ganesh and Srinivas [9] examined the evaluation of thermodynamic properties of a mixture of ammonia water up to 100 Bars for power application systems. They made new MatLab code to calculate the thermodynamic properties that would be used to simulate the Kalina cycle. Developed in MatLab, the program allows quick calculation of thermodynamic properties. The correlations suggested by Ziegler and Trepp [10], Patek et al. [11] were used to calculate feature diagrams in MatLab. Anusha and Chaitanya, [12] evaluated the performance analysis of absorption cooling cycles. They performed thermodynamic analysis of the combination of these three absorption pairs, NH<sub>3</sub> / H<sub>2</sub>O, NH<sub>3</sub> / LiNO<sub>3</sub>, NH<sub>3</sub> / NaSCN. They showed that ammonia / NaSCN and ammonia / LiNO<sub>3</sub> outperformed the ammonia / H<sub>2</sub>O pair.

In this study, the first and second law analyses of the system were carried out by mathematical modelling of system components and a single stage single-exchanger absorbing cooling system. Analyses were repeated with different refrigerant pairs and mathematical model created in a computer program with numerical calculation was used to compare system performance values and exergy losses of system elements.

## 2. System Description

Figure 1 shows a schematic view of the absorption cooling system in which thermodynamics and exergy analyzes for different solution pairs are performed. By means of the heat given to the solution in the generator, the working fluid having a lower saturation temperature is separated from the solution and passes to the condenser. The vaporized fluid becomes liquid by giving heat in the condenser. At high pressure, the pressure of the liquid working fluid is reduced in the expansion valve to the evaporator, where it evaporates by taking heat from the environment. The fluid vapor then goes into the absorber and joins the solution from the generator. Heat should be withdrawn from the absorber at this time. The solution in the absorber is passed through the heat exchanger by means of a liquid pump and receives some heat and is sent to the generator. The cycle continues.



**Figure 1.** Schematic view of the absorption cooling system

The following assumptions were made in the mathematical model for the system analysis:

1. The pressure in the condenser and the generator is the saturation pressure at which the refrigerant is at the condenser temperature.
2. The pressure in the absorber and evaporator is the saturation pressure at which the refrigerant vapor is at the evaporator temperature.
3. The pressure and temperature of the refrigerant when it is separated from the generator is the pressure and temperature of the generator.
4. The phase of the refrigerant is saturated liquid ( $X = 0$ ), separating from the condenser.
5. When the phase of the refrigerant is separated from the evaporator, it is saturated steam ( $X=1$ ).
6. When the solution is separated from the absorber, the absorber is in equilibrium in temperature and pressure.
7. The output temperature of the solution from the absorber is equal to the outlet temperature of the refrigerant from the condenser ( $T_5 = T_2$ )
8. Pump power is too small for that has been ignored.

## 3. Thermodynamic Analysis of the System

In an absorptive cooling system using the LiBr-H<sub>2</sub>O solution, the refrigerant is H<sub>2</sub>O. For systems using NH<sub>3</sub>-H<sub>2</sub>O, NH<sub>3</sub>-LiNO<sub>3</sub>, NH<sub>3</sub>-NaSCN solutions, the refrigerant is NH<sub>3</sub>. In the system using the LiBr-H<sub>2</sub>O solution, the concentration depends on the amount of LiBr; In NH<sub>3</sub>-H<sub>2</sub>O, NH<sub>3</sub>-LiNO<sub>3</sub>,

$\text{NH}_3\text{-NaSCN}$  solutions the concentration is determined by the amount of  $\text{NH}_3$ . For this reason, while the rich solution concept in the system using the  $\text{LiBr-H}_2\text{O}$  solution is described at the outlet of the generator that evaporates the refrigerant, In systems using  $\text{NH}_3\text{-H}_2\text{O}$ ,  $\text{NH}_3\text{-LiNO}_3$ ,  $\text{NH}_3\text{-NaSCN}$  solutions, it is defined at the generator inlet that the amount of refrigerant is concentrated in the solution. The energy equations are given for these two different cases where the circulation ratio ( $f$ ) is calculated with different equations. The exchanger efficiency is given by Equation (1):

$$\varepsilon = \frac{T_8 - T_9}{T_8 - T_6} \quad (1)$$

Exergy ( $E_q$ ) resulting from heat interactions, exergy ( $E_w$ ) resulting from work interactions, and the exergy ( $E$ , (in units of kW)) that enters and exits depending on the mass flow is as described as follows:

$$E_q = \sum \left(1 - \frac{T_0}{T}\right) Q \quad (2)$$

$$E_w = \sum \dot{W} \quad (3)$$

$$E = \sum (\dot{m}\Psi) \quad (4)$$

The specific exergy is found by the following equation:

$$\Psi = \Psi^{ph} + \Psi^{ch} \quad (5)$$

The ph given in equation (5) is used to describe the physical state of the specific exergy, while the ch index is used to describe the chemical state of the specific exergy.

In this study, chemical exergy was not considered because there was no change in the chemical structure of the fluid couple. Physical exergy is as follows:

$$\Psi^{ph} = (h - h_0) - T_0(s - s_0) \quad (6)$$

In equation (6),  $h_0$  and  $s_0$  represent the enthalpy and entropy quantities of the dead-state pressure and temperature, respectively. In this study, 101.325 kPa and 25 °C values were accepted as the dead-state. The COP and exergy efficiency ( $\eta_{II}$ ) of an overall cycle and can be expressed as follows:

$$COP = \frac{Q_e}{Q_g} \quad (7)$$

$$\eta_{II} = \frac{E_e}{E_g} \times 100 \quad (8)$$

The energy and exergy equations are given in Table 1 for of each component.

#### 4. Results and Discussion

Thermodynamics and exergy analysis were performed for  $\text{LiBr-H}_2\text{O}$ ,  $\text{NH}_3\text{-H}_2\text{O}$ ,  $\text{NH}_3\text{-LiNO}_3$  and  $\text{NH}_3\text{-NaSCN}$  fluid pairs in an absorptive cooling system schematically shown in Figure 1. For the analysis, a mathematical model was developed in the computer program of numerical computation and the coefficient of performance (COP) and excitation efficiencies (%) in different generator, evaporator and absorber temperatures were examined separately for each fluid pair.

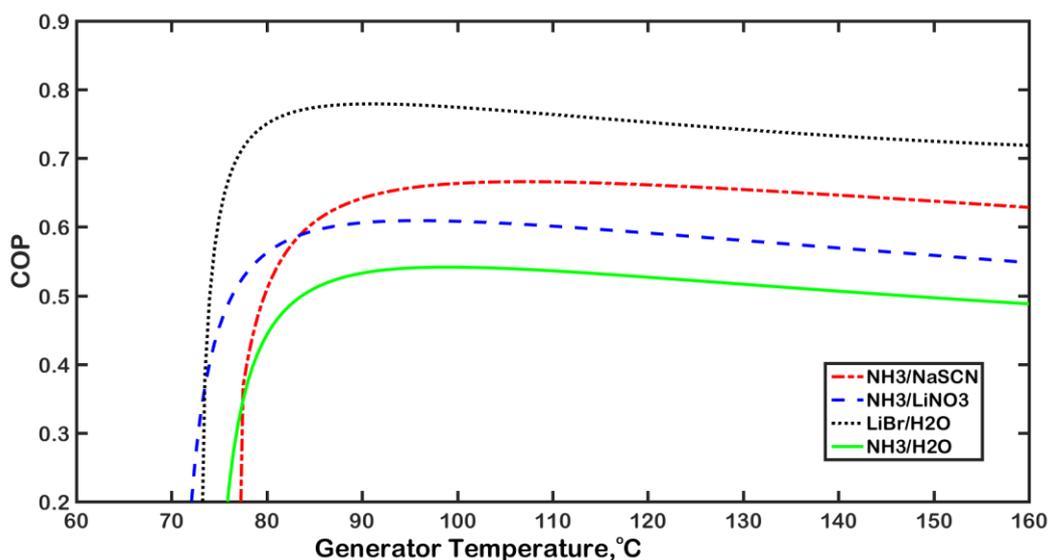
**Table 1.** For of each component mass, energy, and exergy equations

Component	Mass Equation	Energy and Exergy Equation
Absorber	$\dot{m}_5 = \dot{m}_4 + \dot{m}_{10}$	<b>Energy Equation</b> for NH <sub>3</sub> -H <sub>2</sub> O, NH <sub>3</sub> -LiNO <sub>3</sub> , NH <sub>3</sub> -NaSCN solutions $f = \frac{(1-x_8)}{(x_7-x_8)}$ $Q_{abs} = f \cdot h_5 - h_4 - (f - 1) \cdot h_{10}$ for LiBr-H <sub>2</sub> O solution $f = \frac{x_7}{(x_8-x_7)}$ $Q_{abs} = (f + 1) \cdot h_5 - h_4 - f \cdot h_{10}$
		<b>Exergy Equation</b> $I_{abs} = E_{10} + E_4 - E_5 + E_{qabs}$
Pump	$\dot{m}_5 = \dot{m}_6$	<b>Energy Equation</b> $X_5=X_6$ $h_5=h_6$
		<b>Exergy Equation</b> $I_p = E_5 - E_6 + W_p$
Expansion Valve1	$\dot{m}_9 = \dot{m}_{10}$	<b>Energy Equation</b> $X_9=X_{10}$ $h_9=h_{10}$
		<b>Exergy Equation</b> $I_{ev1} = E_9 - E_{10}$
Heat exchanger	$\dot{m}_7 = \dot{m}_6$ $\dot{m}_8 = \dot{m}_9$	<b>Energy Equation</b> $X_6=X_7$ $X_8=X_9$ $\dot{m}_7 \cdot h_7 + \dot{m}_9 \cdot h_9 = \dot{m}_6 \cdot h_6 + \dot{m}_8 \cdot h_8$
		<b>Exergy Equation</b> $I_{ex} = E_6 + E_8 - (E_7 + E_9)$
Generator	$\dot{m}_7 = \dot{m}_1 + \dot{m}_8$	<b>Energy Equation</b> for NH <sub>3</sub> -H <sub>2</sub> O, NH <sub>3</sub> -LiNO <sub>3</sub> , NH <sub>3</sub> -NaSCN solutions $Q_g = h_1 + (f - 1) \cdot h_8 - f \cdot h_7$ for LiBr-H <sub>2</sub> O solution $Q_g = f \cdot h_8 + h_1 - (f + 1) \cdot h_7$
		<b>Exergy Equation</b> $I_g = E_7 - E_1 - E_8 + E_{qg}$
Condenser	$\dot{m}_1 = \dot{m}_2$	<b>Energy Equation</b> $Q_c = \dot{m}_1(h_1 - h_2)$
		<b>Exergy Equation</b> $I_c = E_1 - E_2 + E_{qc}$
Expansion Valve2	$\dot{m}_2 = \dot{m}_3$	<b>Energy Equation</b> $h_2 = h_3$
		<b>Exergy Equation</b> $I_{ev2} = E_2 - E_3$
Evaporator	$\dot{m}_3 = \dot{m}_4$	<b>Energy Equation</b> $Q_{evp} = \dot{m}_3(h_4 - h_3)$
		<b>Exergy Equation</b> $I_{evp} = E_3 - E_4 + E_{qevp}$

#### 4.1 Effect of Generator Temperature on the Performance of the Absorptive Cooling System

In Figure 2, the effect of the generator temperature on the performance coefficient (COP) of the absorptive cooling system is shown for different solution pairs.  $T_e = 10^\circ\text{C}$  and  $T_{\text{abs}} = T_c = 40^\circ\text{C}$  for graphical drawing.  $T_e$ ,  $T_{\text{abs}}$  and  $T_c$  respectively show the evaporator temperature, absorber temperature and condenser temperature. The reason why these values are taken is the need to compare the mathematical model compatibility with the work done by Farshi et al. [7] and the need to verify the model with this approach.

The reason why these values are taken is the need to compare the mathematical model compatibility with the work. Farshi et al. [7] found COP values for  $\text{NH}_3\text{-NaSCN}$  and  $\text{NH}_3\text{-LiNO}_3$  fluid pairs at the same conditions, respectively, at the generator temperatures of 0.6 and 0.53, respectively, at  $113^\circ\text{C}$ . In this study, the COP value for the  $\text{NH}_3\text{-NaSCN}$  fluid couple was found at a maximum temperature of  $106^\circ\text{C}$  at 0.66 and at the highest COP value of 0.6 for the  $\text{NH}_3\text{-LiNO}_3$  fluid couple at  $96^\circ\text{C}$  generator temperature.



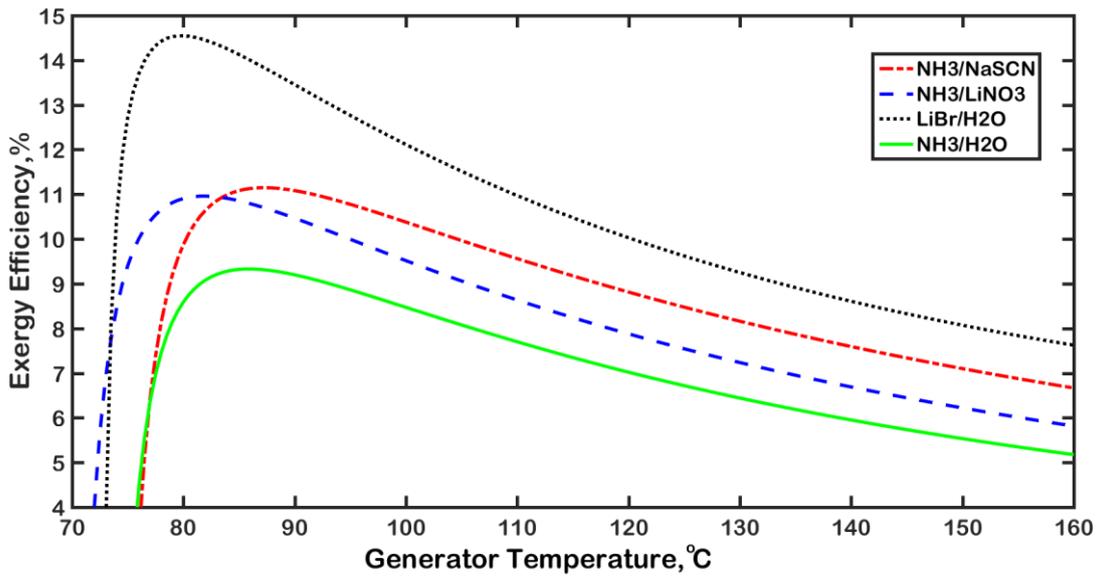
**Figure 2.** Effect of generator temperature on COP

In addition to the solution pairs that Farshi et al. [7] have studied,  $\text{LiBr-H}_2\text{O}$  and  $\text{NH}_3\text{-H}_2\text{O}$  have been studied in this study. In the graph in Figure 2, the  $\text{LiBr-H}_2\text{O}$  fluid pairs have the highest COP values for the same generator temperature. When the fluid pairs using ammonia ( $\text{NH}_3$ ) as the refrigerant are compared among themselves, it is seen that the absorbent  $\text{NaSCN}$  has the highest COP values.

As the generator temperature increases, the COP values increase first in all the fluid pairs and then the COP values decrease. This result is consistent with the works of Abdulateef et al. [3], Florides and Kalogirou [2], Farshi et al. [7].

In Figure 3, as the generator temperature increases, the exergy efficiency of the system increases before and then decreases for solution fluid pairs. Increasing the generator temperature reduces the circulation rate, which causes the generator capacity to decrease and thus increases the efficiency of exergy. At a higher temperature than the generator temperature range of about  $80\text{-}85^\circ\text{C}$ , the exergy efficiency of the fluid couple began to decline. Increasing the generator temperature while the evaporator temperature is kept constant, caused the increase of the exergy entering the system. This reduces the efficiency of exergy. As the temperature of the heat source increases, cooling at lower

temperatures can be achieved. Exergy efficiency value of the LiBr-H<sub>2</sub>O fluid couple is the highest value when changing the generator temperature.

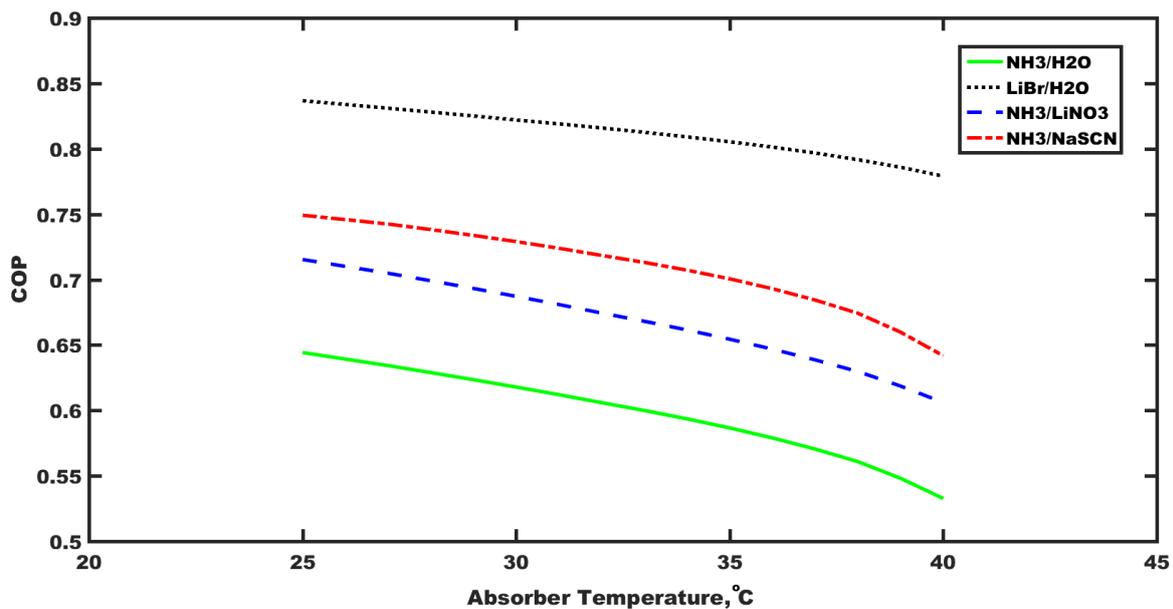


**Figure 3.** Effect of generator temperature on exergy efficiency

When the fluid pairs using ammonia (NH<sub>3</sub>) as the refrigerant are compared among themselves, the NH<sub>3</sub>-NaSCN fluid couple has the highest exergy efficiency.

**4.2 Effect of Absorber Temperature on the Performance of the Absorptive Cooling System**

Figure 4 and Figure 5 show the effect of the performance coefficient (COP) and the exergy efficiency on the different absorber temperatures of the fluid pairs. The increase in absorber temperature leads to an increase in the flow rate by reducing the difference between the poor and rich solution concentration. As the evaporator temperature and the absorber pressure are kept constant, the flow rate increases as the absorber temperature increases.



**Figure 4.** Effect of absorber temperature on COP

Increasing the flow rate decreases the performance coefficient of the system by increasing the generator capacity. The increase of the generator capacity increased the exergy entering the system and the increase of the entering exergy while the cooling load was constant caused the decrease of the exergy efficiency of the system. This situation, which is observed from Figure 4 and Figure 5, is consistent with that of Kaushik and Arora [13].

In the absorber temperature range shown in Figure 4 and Figure 5, LiBr-H<sub>2</sub>O is the fluid couple with the highest COP value and exergy efficiency. When Fluid pairs using ammonia (NH<sub>3</sub>) as the refrigerant are compared with each other, the NH<sub>3</sub>-NaSCN fluid couple has the highest COP value and exergy efficiency. This result is consistent with the works of Kaushik and Arora [13] and Dehua et al. [14].

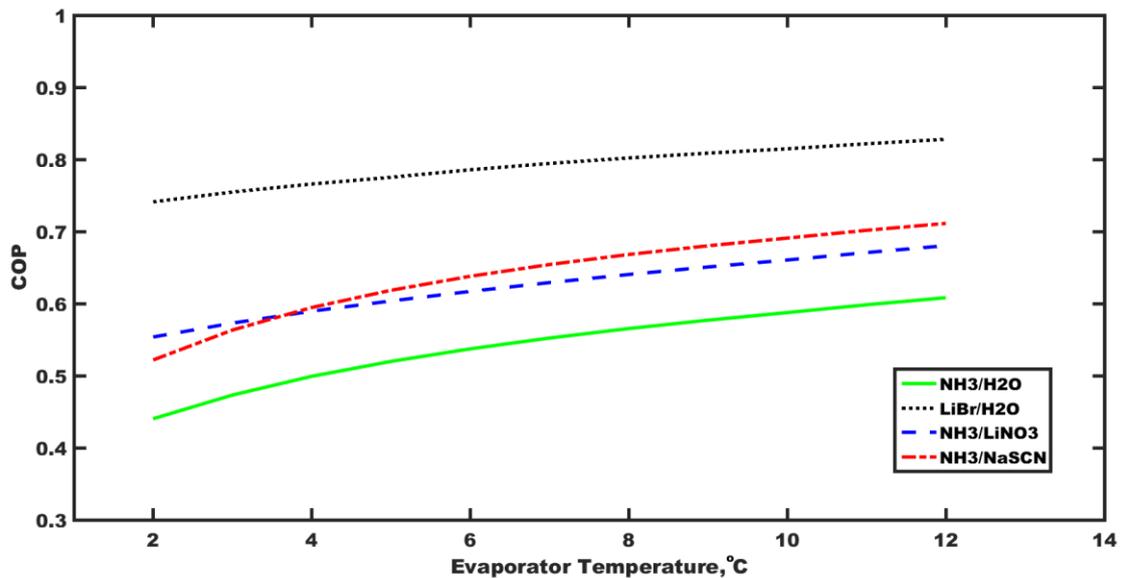


Figure 5. Effect of absorber temperature on exergy efficiency

### 4.3 Effect of Evaporator Temperature on the Performance of the Absorptive Cooling System

Figure 6 shows the variation of performance coefficient (COP) at different evaporator temperatures.

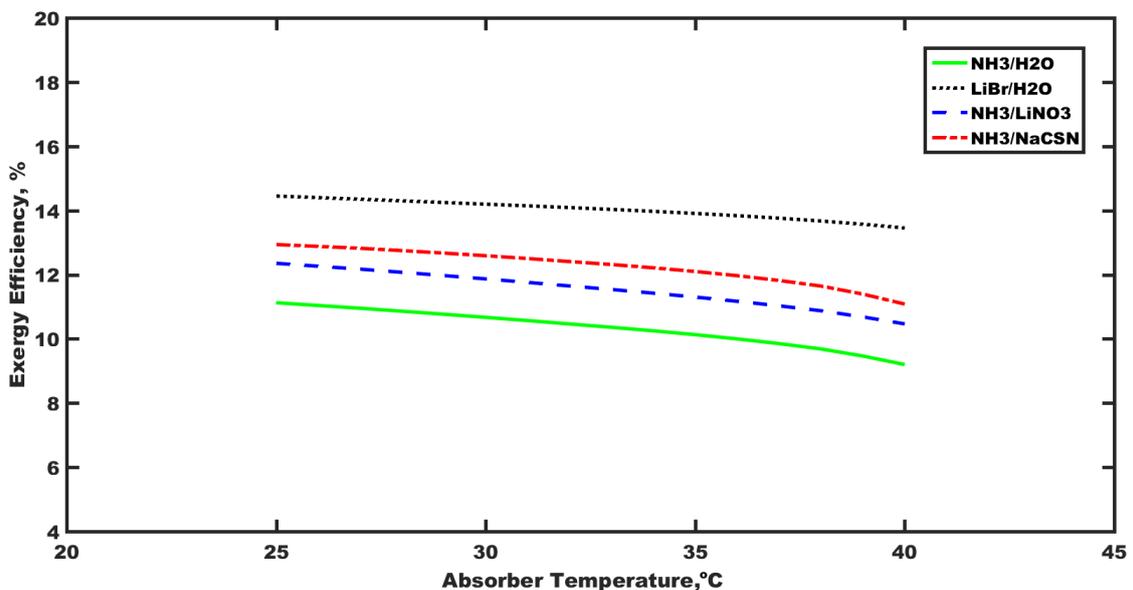


Figure 6. Effect of evaporator temperature on COP

As the evaporator temperature increases, the performance coefficient of the absorption cooling system increases.

The increase in evaporator temperatures increases the difference between rich and poor solution concentrations and thus reduces the circulation rate. As the value of the circulation rate decreases, the generator capacity decreases and COP increases. In addition, since the generator temperature and the condenser pressure are kept constant, the evaporator temperature increases while the COP value also increases. These results are consistent with the results of Kaushik and Arora's work [13]. In the evaporator temperature range shown in Figure 6, LiBr-H<sub>2</sub>O is the fluid couple with the highest COP value. When Fluid pairs using ammonia (NH<sub>3</sub>) as the refrigerant are compared with each other, the NH<sub>3</sub>-NaSCN fluid couple has the highest COP value. This result is consistent with that of Kaushik and Arora [13], Dehua et al. [14]. Figure 7 shows that the exergy efficiency of the absorption cooling system decreases with increasing evaporator temperature. The exergy efficiency of NH<sub>3</sub>-NaSCN solution is greater than the exergy efficiency of the NH<sub>3</sub>-LiNO<sub>3</sub> solution at values greater than 4 °C evaporator temperature. In addition, in the evaporator temperature range shown in

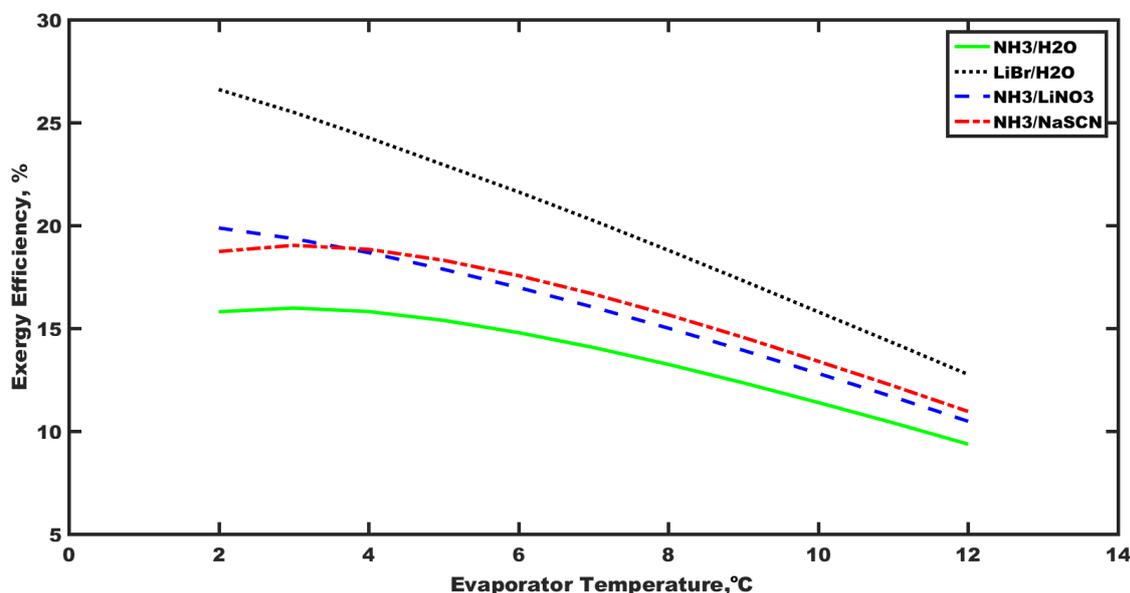


Figure 7. Effect of evaporator temperature on exergy efficiency

## 5. Conclusions

In this study, the first and second law analyzes of the system were carried out by mathematically modeling for different solution pairs in a single-stage single-exchanger absorbing cooling system. The aim of this study was to determine solution pairs giving the best COP value and the the exergy efficiency value in an absorption cooling system. In addition, a mathematical model has been developed in MATLAB computer program which conducts energy and exergy analysis of absorption cooling system. As a continuation of this study, a thermo-economic analysis of the different solution pairs will be useful in the selection of a fluid pair for the absorption cooling system in practice.

The results of the analyzes are as follows;

1. It has been observed that increasing the generator temperature in the absorptive refrigeration system increases the coefficient of operation and the exergy efficiency of the system. However, as the generator temperature increases more and more, the performance coefficient of the system and the exergy efficiency have begun to decrease.

2. The increase in the absorber temperature leads to an increase in the flow rate by reducing the difference between the poor and rich solution concentration. Therefore, as the absorber temperature increased, the COP value and exergy efficiency decreased, and the irreversibility of the system was observed to increase.
3. With increasing evaporator temperature, the COP value was also increased, but the same effect was not observed in the change of exergy efficiency value. Increasing the evaporator temperature has increased the irreversibility of the system. Thus, the exergy efficiency of the system has been reduced by increasing the evaporator temperature.
4. The LiBr-H<sub>2</sub>O solution pair showed better performance (higher COP and exergy efficiency) than the other solution pairs (NH<sub>3</sub>-H<sub>2</sub>O, NH<sub>3</sub>-LiNO<sub>3</sub>, NH<sub>3</sub>-NaSCN).
5. When solution pairs using ammonia as a refrigerant are evaluated among themselves, NaSCN absorbent has the highest COP and exergy efficiency values.

### Acknowledgement

This study consists of a part of the second author's thesis [20].

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