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Performance Analysis of A Single Stage Absorption Cooling System at Different Operating Temperatures

A. Burak YAVUZ[1], Osman KARA[2*], Bülent YANIKTEPE[3]

[1]Osmaniye Korkut Ata University, Kadirli Vocational School of Higher Education, Department of Mechanical, 80010, Osmaniye
[2,3]Osmaniye Korkut Ata University, Faculty of Engineering, Department of Energy Systems Engineering, 80010, Osmaniye

[1]https://orcid.org/0000-0002-8267-3086
[2]https://orcid.org/0000-0003-1501-677X
[3]https://orcid.org/0000-0001-8958-4687
* Corresponding author: osmankara@osmaniye.edu.tr

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ABSTRACT

Today, rapid developments are experienced in terms of energy consumption and energy efficiency in air conditioning systems. Among these systems, waste heat and renewable energy sources are used in absorption cooling systems. Although the initial investment cost of this system is high, the operating cost is low due to the use of waste heat. In this study, the effect of generator, condenser, absorber and evaporator temperatures on system performance (COP) in absorption cooling systems operating with single-stage $LiBr-H_2O$ fluid pair was investigated. The temperature effect was investigated using energy balances with the help of thermodynamic equations. It was found from the results that the system performance (COP) increased with increasing the generator temperature, and the system performance (COP) decreased with increasing the condenser and absorber temperatures. In addition, it was determined that the $LiBr-H_2O$ solution temperature and concentration changed in the system examined at different generator, condenser, absorber and evaporator temperatures, and crystallization occurred accordingly in some parameters.

Tek Kademeli Absorbsiyonlu Soğutma Sisteminin Farklı Çalışma Sıcaklıklarındaki Performans Analizi

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ÖZET

Günümüzde, İklimlendirme sistemlerinde enerji tüketimi ve enerji verimliliği açısından hızlı gelişmeler yaşanmaktadır. Bu sistemler içerisinde absorpsiyonlu soğutma sistemlerin de atık ısı ve yenilenebilir enerji kaynakları kullanılmaktadır. Bu sistemin ilk yatırım maliyetinin yüksek olmasına rağmen, atık ısı kullanımından dolayı işletme maliyeti düşüktür. Bu çalışmada tek kademeli $LiBr-H_2O$ akışkan çifti ile çalışan absorbsiyonlu soğutma sistemlerinde ısıtıcı, yoğuşturucu, soğurucu ve buharlaştırıcı sıcaklıklarının sistem performansı üzerine etkisi (COP) incelenmiştir. Sıcaklık etkisi termodinamik eşitlikler yardımı ile enerji denklikleri kullanılarak araştırılmıştır. Jenaratör sıcaklığının arttırılması ile sistem performansının (COP) arttığı, yoğuşturucu ve soğurucu sıcaklıklarının arttırılması ile sistem performansının (COP) azaldığı bulunmuştur. Ayrıca farklı jenaratör, yoğuşturucu, soğurucu ve buharlaştırıcı sıcaklıklarında incelenen sistemde $LiBr-H_2O$ eriyik sıcaklığının ve konsantrasyonun değiştiği, buna bağlı olarak bazı parametrelerde kristalizasyonun oluştuğu tespit edilmiştir.

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Introduction

In recent years, with the increasing population and technological developments, the need for energy has also increased. Accordingly, increasing energy consumption has a negative effect on climate change, global warming and the decrease in energy reserves. In many areas, studies are carried out to reduce energy consumption or to use renewable energy sources (Yaniktepe, 2017). In particular, due to the intensive use of cooling systems both in daily life and in industrial facilities and in order to save energy, studies on this area have recently intensified (Özen, 2019). Absorption cooling systems have been developed due to the high electrical energy consumption in vapor compression cooling systems. In absorption cooling systems, energy saving is achieved by using energy sources such as solar energy, geothermal energy and waste heat (Cimşit, 2018). In absorption cooling systems, the electricity consumption demand is very low in the operation of the system with the use of renewable energy sources or the recovery of waste energy. Absorption cooling systems working with a single-stage $LiBr - H_2O$ fluid couple are one of the most widely used absorption cooling systems (Avanessian, 2014).

In the literature review on the subject, Kaynakli and Yamankaradeniz examined single-stage absorption cooling systems working with $LiBr - H_2O$ and $NH_3 - H_2O$ fluid pairs. They stated that under the same temperature conditions, the system using $LiBr - H_2O$ fluid couple is more efficient than the system using $NH_3 - H_2O$ fluid couple, but crystallization formation occurs at high generator temperatures in systems using $LiBr - H_2O$ fluid couple (Kaynakli and Yamankaradeniz, 2003). Liu et al. investigated the use of low-grade waste heat energy in the range of 90-150 ℃ of the absorption refrigeration system operating with $LiBr - H_2O$ fluid couple. They simulated various cooling temperatures and pressures (Liu et al., 2019). Han et al. investigated an absorption cooling system operating with $LiBr - H_2O$ fluid couple, which uses geothermal energy to cool a room where information communication technology devices are located. The temperatures of geothermal energy sources can reach 150 ℃ and above, and the places where information communication technology devices are located need to be cooled at all hours of the day. Therefore, they stated that absorption cooling technologies with geothermal resources can be used in places where cooling is needed (Han et al., 2020).

Erdinç et al. simulated an absorption cooling system working with a $LiBr - H_2O$ fluid couple. The effects of hot water, cooling water and water to be cooled temperatures on system performance were investigated (Erdinç et al., 2020). Alejandro et al. investigated a single-stage LiBr absorption chiller operated with a low heat source temperature. In their study, the authors developed an optimal control technique and significantly improved the system COP (Alejandro et al., 2018).

Kızılkan et al. investigated the thermoeconomic optimization of absorption cooling systems operating with $LiBr - H_2O$ fluid couple. Thermoeconomic optimization study was carried out to determine the optimum operating parameters of the system. It is important to determine the optimum operating parameters of a system. The authors optimized the main equipment of the absorption cooling system such as condenser, evaporator, generator, absorber heat exchangers. They also stated that the system performance should be calculated by considering not only economical but also thermodynamic properties while determining the optimum area. (Kızılkan et al., 2007). Soliman et al. investigated the operation of vehicle air conditioners using exhaust gas with a new generator design. They stated that absorption cooling systems working with $LiBr - H_2O$ fluid couple, using the exhaust gas temperature with the generator design, can operate at low engine speeds (Soliman et al., 2021).

In this study, the effect of generator, condenser, absorber and evaporator temperatures on the system performance (COP) in absorption refrigeration systems operating with a single-stage $LiBr - H_2O$ fluid couple was calculated with thermodynamic equations. In addition, the effects of different generator, condenser, absorber and evaporator temperatures on $LiBr - H_2O$ solution temperature and concentration were investigated, and accordingly, the temperatures at which crystallization occurred were determined.

Materials and Methods

The schematic representation of the absorption cooling system working with a single-stage $LiBr - H_2O$ fluid couple is shown in Figure 1. Cycle points are specified on the system. Considering the schematic representation of the absorption cooling system, the thermal capacities of the elements in the system were calculated using thermodynamic equations.

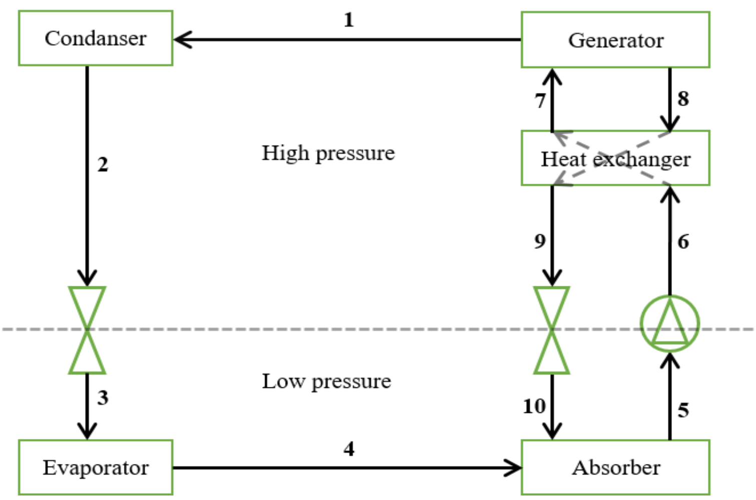

Figure 1. Schematic diagram of single state absorption refrigeration system

The capacities per unit mass of the evaporator and condenser were calculated using thermodynamic equations. Thermodynamic equations are given below.

$$q_{eva} = (h_4 - h_3) \quad (1)$$

$$q_{con} = (h_2 - h_1) \quad (2)$$

While calculating the generator capacity per unit mass, the heat exchanger balance, mass balances, rich solution concentration and lean solution concentration values were used (Kaynaklı and Yamankaradeniz, 2003).

$$m_7 = m_8 + m_1 \quad (3)$$

$$m_7 x_7 = m_8 x_8 \quad (4)$$

$$W_z = \frac{m_8}{m_1} = \frac{x_7}{x_8 - x_7} \quad (5)$$

$$W_f = \frac{m_7}{m_1} = \frac{x_8}{x_8 - x_7} \quad (6)$$

$$W_z(h_8 - h_9) = W_f(h_7 - h_6) \quad (7)$$

$$Q_{gen} = m_1 h_1 + m_8 h_8 - m_7 h_7 \quad (8)$$

$$q_{gen} = h_1 + W_z h_8 - W_f h_7 \quad (9)$$

Mass balances were used when calculating the capacity of the absorber per unit mass. The heat losses of the equipment in the system and the pump power can be neglected because they are of very small value (Avanessian, 2014). Accordingly, the system performance coefficient can be calculated with the following equations (Horuz, 1990).

$$Q_{abs} = m_5 h_5 - m_4 h_4 - m_{10} h_{10} \quad (11)$$

$$q_{abs} = W_f h_5 - h_4 - W_z h_{10} \quad (12)$$

$$COP = \frac{Q_{eva}}{Q_{gen}} \quad (13)$$

Results and Discussion

While determining the performance of the absorption cooling system working with a single-stage $LiBr - H_2O$ fluid couple, thermodynamic balances and mass balances were written with a computer program. The effects of thermodynamic values of evaporator, condenser, absorber, and generator at different temperatures on the cycle and system performance were investigated. Generator temperature 80℃, evaporator temperature 10℃, absorber and condenser temperature 40℃, the high pressure and the low pressure of cycle are taken 7.38 kPa, 1.22 kPa, respectively. Table 1 shows the temperature, pressure, enthalpy and concentration values of the cycle. The heat exchanger efficiency coefficient was accepted as 0.6. Table 2 shows the thermal capacities and system performance of the equipment in the system.

Table 1. Temperature and pressure values of system states

States	T (℃)	P (kPa)	h (kJ/kg)	X (%)
1	80,00	7,38	2643,00	-
2	40,00	7,38	167,53	-
3	10,00	1,22	167,53	-
4	10,00	1,22	2519,20	-
5	40,00	1,22	93,17	54,83
6	40,00	7,38	93,17	54,83
7	66,03	7,38	145,15	54,83
8	80,00	7,38	184,11	57,65
9	52,68	7,38	129,54	57,65
10	52,68	1,22	145,15	57,65

Table 2. Equipment capacities and system performance

Equipment	Thermal Capacities (kJ/kg)
Generator	3284,44
Condenser	2475,47
Evaporator	2351,47
Absorber	3160,44
COP	0,72

As seen in Table 2, the highest thermal capacity belongs to the generator among the equipment in the system. In addition to the temperature and enthalpy values of the generator, the rich and poor solution concentration values of the $LiBr - H_2O$ fluid couple also affect the generator thermal capacity. In Figure 2, concentration values are shown on the $LiBr - H_2O$ crystallization curve.

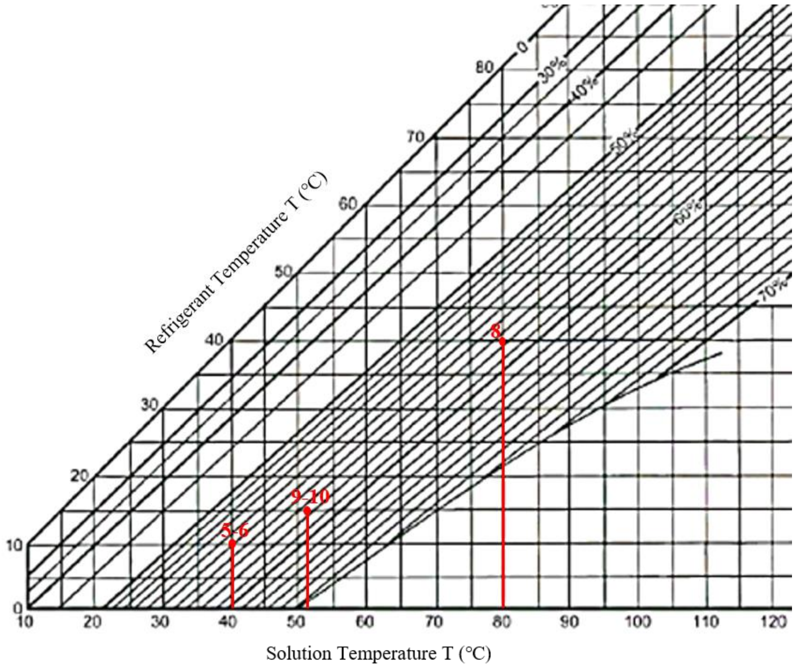

Figure 2. Crystallization curve of $LiBr - H_2O$ (Liao, 2014)

The effect of different generator temperatures on system performance is shown in Figure 3. While examining the effect of generator temperature on system performance, the evaporator temperature was taken as 10°C and the absorber and condenser temperature was taken as 40°C. As seen in Figure 3, the system performance increases as the generator temperature increases. However, if the generator temperature rises above 90°C, crystallization occurs. In the system, it was observed that the poor solution concentration remained constant with the increase in generator temperature. It was observed that the rich concentration increased depending on the generator temperature.

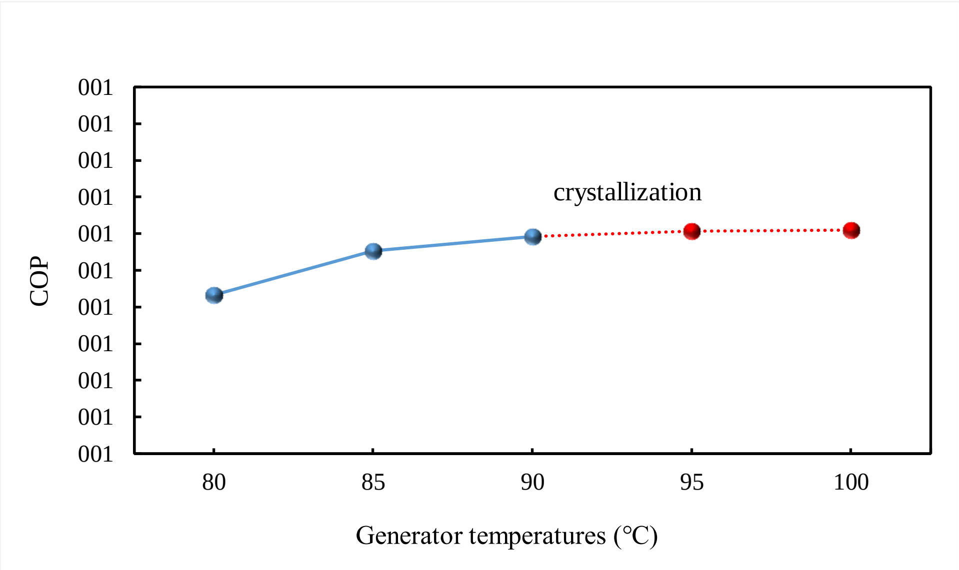

Figure 3. Effect of generator temperature on system performance

Figure 4 shows the effect of condenser and absorber temperature on system performance. While examining the effect of condenser and absorber temperatures on system performance, the evaporator temperature was taken as 10°C and the generator temperature was 80°C. The variation range of the condenser and absorber temperatures was taken as the same value. It was observed that the performance of the system decreased with increasing the condenser and absorber temperature. Although the system performance is high at low temperatures, crystallization occurs when the temperature drops below 35°C. This result shows a close agreement with that reported in the literature (Özen, 2019).

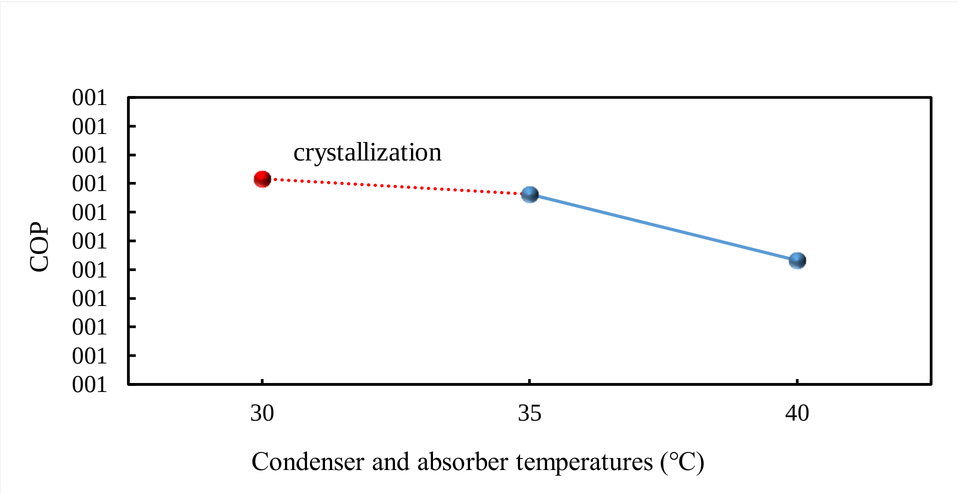

Figure 4. Effect of condenser and absorber temperature on system performance

The effect of evaporator temperature on system performance is shown in Figure 5. While examining the effect of evaporator temperature on system performance, generator temperature was taken as 80°C, absorber and condenser temperature was taken as 40°C. It was observed that the performance of the system increased with increasing the evaporator temperature. No risk of crystallization was encountered at the temperature values studied. The poor solution concentration increases with decreasing evaporator temperature. However, as the evaporator temperature drops below 7°C, the rich solution concentration and the poor solution concentration are very close to each other. In addition, it was observed that there was a sudden decrease in system performance as a result of the evaporator temperature below 7°C. The same trends were achieved by Kaynakli and Yamankaradeniz (Kaynakli and Yamankaradeniz, 2003).

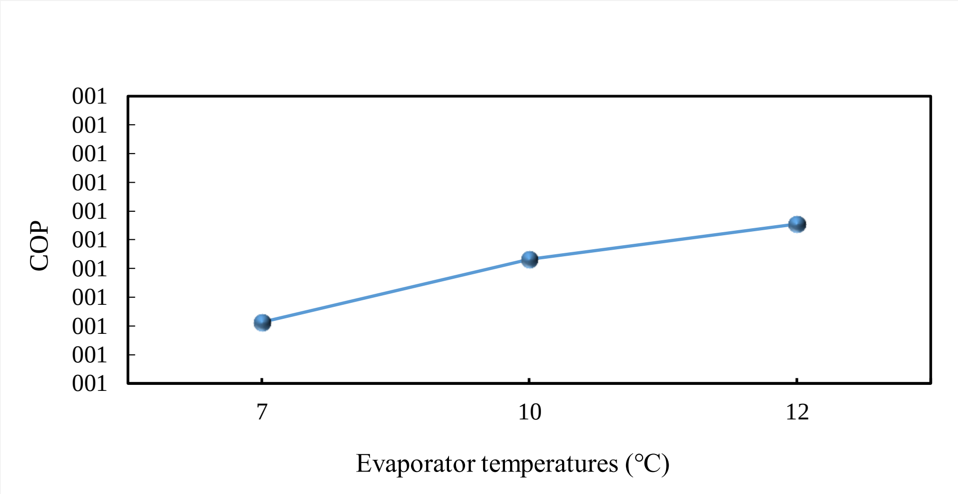

Figure 5. Effect of evaporator temperature on system performance

Conclusion

In this study, the effect of heater, condenser, absorber and evaporator temperatures on system performance (COP) in absorption cooling systems operating with a single-stage $LiBr - H_2O$ fluid couple was investigated. With the thermodynamic equations, it was observed that the system performance (COP) increases with increasing the generator and evaporator temperature in the system, and the system performance (COP) decreases with increasing the condenser and absorber temperatures. One of the biggest problems encountered in absorption cooling systems working with $LiBr - H_2O$ fluid couple is the danger of crystallization. In the examined system, crystallization occurs as a result of high generator temperatures. As the generator temperature increases, the rich concentration and the solution temperature at the generator inlet increase. If the rich solution concentration exceeds 70%, crystallization occurs. Depending on the heat exchanger efficiency coefficient, crystallization occurs when the condenser temperature is lower than 35°C. Therefore, in absorption cooling systems working with $LiBr - H_2O$ fluid couple, system design should be done at optimum temperatures, taking into account the formation of crystallization, regardless of system performance.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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Symbols

		subscripts	
T	: Temperature, °C	abs	: Absorber
Q	: Termal power, kW	gen	: Generator
q	: Thermal capacity per unit mass, kJ/kg	con	: Condenser
X	: Concentration	eva	: Evaporator
m	: Mass flow rate, kg/s	f	: Poor solution
P	: Pressure, kPa	z	: Rich solution

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