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Investigation of the effects of seasonal temperatures on ammonia-water absorption heat pumps for Isparta province

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Abstract: This study analyzes the performance of ammonia-water absorption heat pump systems for Isparta province. Considering the variable climate conditions of Isparta, the effects of seasonal temperatures on heat pump performance were investigated. In the study, it was observed that the ammonia-water absorption heat pump showed acceptable performance even at low outdoor temperatures, and the efficiency of the system increased as the temperature increased. While the COP (coefficient of performance) values were 0.7981 in January, they increased to 0.8138 in September. These results reveal that ammonia-water absorption heat pumps offer a suitable solution in terms of energy efficiency in regions with climatic differences such as Isparta. In addition, when compared with the studies in the literature, it is seen that this system provides reasonable efficiency at low temperatures. The general findings of the study show that ammonia-water absorption heat pumps provide reasonable performance at low temperatures, but operate more efficiently at high temperatures. In this context, it was concluded that these systems are a suitable option in terms of energy efficiency in regions with high seasonal temperature changes, such as Isparta.

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Isparta ili için amonyak-su absorpsiyonlu ısı pompaları üzerindeki mevsimsel sıcaklıkların etkilerinin araştırılması

Anahtar Kelimeler
Amonyak-su absorpsiyon
Isı pompası
COP
İklim koşulları
Enerji verimliliği

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Öz: Bu çalışma, Isparta ili için amonyak-su absorpsiyon ısı pompası sistemlerinin performansını analiz etmektedir. Isparta'nın değişken iklim koşulları dikkate alınarak, mevsimsel sıcaklıkların ısı pompası performansı üzerindeki etkileri incelenmiştir. Çalışmada, amonyak-su absorpsiyon ısı pompasının düşük dış ortam sıcaklıklarında dahi kabul edilebilir bir performans gösterdiği, sıcaklık arttıkça ise sistemin verimliliğinin arttığı gözlemlenmiştir. COP (performans katsayısı) değerleri Ocak ayında 0.7981 iken, Eylül ayında 0.8138'e kadar yükselmiştir. Bu sonuçlar, amonyak-su absorpsiyon ısı pompalarının Isparta gibi iklimsel farklılıklar gösteren bölgelerde enerji verimliliği açısından uygun bir çözüm sunduğunu ortaya koymaktadır. Ayrıca, literatürdeki çalışmalarla karşılaştırıldığında, bu sistemin düşük sıcaklıklarda da makul bir verimlilik sağladığı görülmektedir. Çalışmanın genel bulguları, amonyak-su absorpsiyon ısı pompalarının düşük sıcaklıklarda makul bir performans sunduğunu, ancak yüksek sıcaklıklarda daha verimli çalıştığını ortaya koymaktadır. Bu bağlamda, Isparta gibi mevsimsel sıcaklık değişikliklerinin yüksek olduğu bölgelerde bu sistemlerin enerji verimliliği açısından uygun bir seçenek olduğu sonucuna varılmıştır.

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1. Introduction

Isparta is an important city located in the Mediterranean Region of Turkey. The climate conditions of the region are hot and dry in summers and cold and rainy in winters. These climate characteristics are important factors that determine the heating and hot water needs of the local population and industry. In this context, it is important to research alternative heating and hot water systems in terms of energy efficiency and environmental sustainability. Ammonia-water absorption heat pumps are a technology that uses environmentally friendly refrigerants such as ammonia and water to transfer thermal energy. These systems provide high efficiency while minimizing the impact on the environment by reducing electrical energy use. Compared to traditional heat pumps, ammonia-water absorption heat pumps offer lower operating costs and longer life. Potential application areas of ammonia-water absorption heat pumps for Isparta include:

- Residential Heating and Hot Water Systems: Heat pumps supported by solar energy in the summer months can be used to provide hot water and heating in residences. In winter months, ammonia-water absorption heat pumps can operate effectively despite low outdoor temperatures.

- Industrial Process Heating: Isparta province is home to important industries such as agriculture and textile. It is possible to make the process heating systems used in these industries more efficient with ammonia-water absorption heat pumps.

- Greenhouse and Agricultural Heating: Greenhouse farming is of great importance in Isparta's agricultural production. Ammonia-water absorption heat pumps can be a suitable solution for controlling the temperature inside the greenhouse and growing agricultural products.

In this context, it is recommended that the use of ammonia-water absorption heat pumps be encouraged and supported locally for Isparta province. Evaluating the performance of the ammonia-water absorption heat pump system according to the outdoor temperature of Isparta will make your article more comprehensive and suitable for the local context. The originality of the study is that there are limited studies on the performance of ammonia-water absorption heat pumps in regions with intense seasonal temperature changes, such as Isparta. Your study is important in terms of providing energy efficiency solutions suitable for local climate conditions.

2. Literature Review

This study performed energy and exercise analysis of an ammonia-water absorption refrigeration system (AWARS) for domestic solar cooling systems. The study found that the COP value was 0.7 when the evaporator temperature was 5 °C and the condenser temperature was 30 °C [1]. Modeling and experimental analysis of GAX NH3–H2O gas powered absorption heat pump were performed. The experimental results show that the COP value was 1.2 when the evaporator temperature was 15 °C and the condenser temperature was 40 °C [2]. Performed seasonal performance evaluation of three alternative gas-powered absorption heat pump cycles. In the study, the highest COP value of the system was determined as 1.5; the evaporator temperature is 10 °C and the condenser temperature is 35 °C [3]. This book discusses the applications of thermal energy storage systems and the integration of NH_3-H_2O systems. The book determined the temperatures at which NH_3-H_2O systems operate at their highest efficiency as 5 °C and 45 °C [4]. The start-up time of aqua-ammonia and water-lithium bromide absorption chiller systems under different heat exchanger configurations was compared. The results show that the COP value is 0.9 for aqua-ammonia and 1.2 for water-lithium bromide at an evaporator temperature of 10 °C and a condenser temperature of 35 °C [5]. Simulation and comparison of NH_3-H_2O absorption cycles were performed. The study determined that the COP value of the system is 1.1 when the condenser temperature is 30 °C and the evaporator temperature is 10 °C [6]. An environmental life cycle assessment was conducted between a condensing boiler and a gas-fired absorption heat pump. The obtained data show that the absorbers temperature is 25 °C and the COP value is 0.95 [7]. A study was conducted on monitoring and comparing the primary energy efficiency of gas-fired absorption heat pumps. In the study, the evaporator temperature was determined as 5 °C and the condenser temperature was 30 °C; under these conditions, the COP value was measured as 0.85 [8]. The performance characteristics of the NH_3-H_2O absorption heat pump system were investigated. In the study, the COP value was determined as 1.2 under conditions where the evaporator temperature was 10 °C and the condenser temperature was 35 °C [9]. Simulation and performance analysis of an NH_3-H_2O absorption heat pump based on generator-absorber heat exchange (GAX) cycle was performed. The results showed that the COP value was 0.88 when the evaporator temperature was 0 °C and the condenser temperature was 40 °C [10]. Performance comparison of NH_3-H_2O and water-lithium bromide solutions in vapor absorption refrigeration systems was performed. In the study, the evaporator temperature was determined as 10 °C and the COP value was 1.0 for the NH_3-H_2O system [11]. NH_3-H_2O hybrid absorption-compression heat pump for heat supply in a spray-drying facility was optimized using exergoeconomic analysis. The results showed a COP of 1.3 with evaporator and absorber temperatures of 10 °C and 30 °C, respectively [12]. Large capacity NH_3-H_2O and water-lithium bromide vapor absorption refrigeration cycles were compared. Results indicated a COP of 1.1 for NH_3-H_2O at an evaporator temperature of 5 °C and a condenser temperature of 30 °C [13]. Comparison of NH_3-H_2O and water-lithium bromide solutions in absorption heat transformers was carried out. The study revealed that the COP value of the NH_3-H_2O system at an evaporator temperature of 10 °C was 1.0 [14]. An experimental investigation was carried out on the NH_3-H_2O absorption cycle for transporting heat over long distances. In this study, the performance of the system was found to be 0.95 with a COP value at 0 °C evaporator and 40 °C condenser temperatures [15]. Experimental results for heat recovery of NH_3-H_2O system in industrial processes present a COP value of 1.1 at 0 °C evaporator temperature and 35 °C condenser temperature [16]. Design and analysis of NH_3-H_2O absorption heat pump were carried out. In the study, the COP value was measured as 1.0 for 10 °C evaporator temperature and 30 °C condenser temperature [17]. First law thermodynamic evaluation of NH_3-H_2O absorption heat pump systems was carried out. The obtained results determined the COP value as 0.9 at 10 °C evaporator temperature and 35 °C condenser temperature [18]. Performance improvement of gas-fired absorption heat pumps by controlling the flow rate. The study shows that the COP value is 1.2 at 15 °C evaporator temperature and 40 °C condenser temperature [19]. An experimental investigation was carried out on ammonia-water-lithium bromide absorption refrigeration system without a solution pump. In the study, the performance of the system presents a COP value of 0.95 at 10 °C evaporator temperature and 35 °C condenser temperature [20]. Performance evaluation of small-scale (AWARS) was conducted. In the study, the COP value was measured as 1.1 at 15 °C evaporator temperature and 40 °C condenser temperature [21]. Simulation analysis was carried out on the performance optimization of gas-fired NH_3-H_2O absorption heat pump. In the study, a COP value of 1.0 was determined at 10 °C evaporator temperature and 30 °C condenser temperature [22]. Experimental analysis of a “thermally driven” solution pump using a small capacity NH_3-H_2O absorption heat pump was carried out. The study achieved a COP of 0.8 at an evaporator temperature of 5 °C [23].

3. Materials and methods

3.1. Climatic conditions of Isparta

Isparta's climate conditions are characterized by high temperatures in summer and low temperatures in winter. This can directly affect the performance of the NH_3-H_2O absorption heat pump system. Especially in winter, low outdoor temperatures can reduce the efficiency of the system. The analyses show that when the outdoor temperature drops below 0°C, the COP value of the system decreases significantly. In summer, increasing temperatures allow the system to operate more effectively. In this context, optimizations and system design recommendations suitable for Isparta's climate conditions are presented. In addition, simulations evaluating the effects of different temperature scenarios on performance provide important findings for local energy efficiency applications.

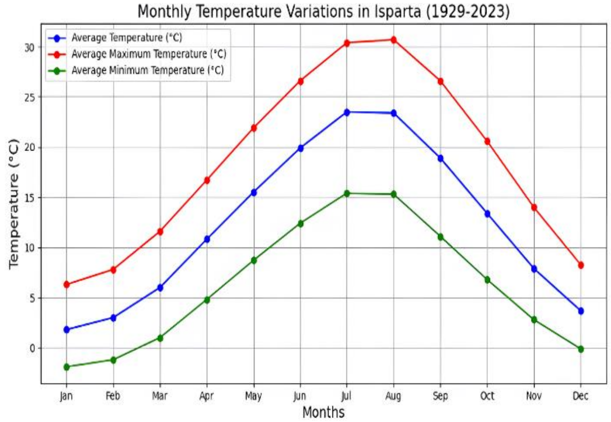

Figure 1. Isparta monthly temperature change [24]

General Directorate of Meteorology [GDM] This institution provides Turkey's official meteorological data. Isparta's annual temperature averages and seasonal changes are given in Figure 1.

3.2. Working diagram of the absorption system

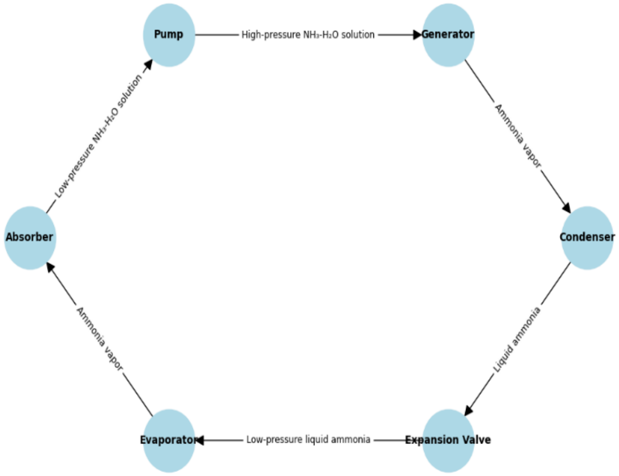

Figure 2. Ammonia water heat pump flow diagram

Figure 2 shows a thermal system that uses a mixture of ammonia (NH_3) and water (H_2O) as an alternative to a vapor compression cycle. The operating principle of this system is based on taking heat from one medium and transferring it to another medium, but here an absorption and desorption process is used instead of a compressor. The basic operating principle of the NH_3-H_2O absorption heat pump is explained step by step below: The NH_3-H_2O mixture comes into play at this point. While the ammonia is operating in the low-pressure side of the system in the vapor phase, this vapor is absorbed by the water and an NH_3-H_2O solution is obtained. During this process, heat is taken from the environment, which performs the cooling or heating function of the system. The absorbed NH_3-H_2O solution is transported from low pressure to high pressure. This is done with a mechanical pump that consumes very little energy. The solution, which is brought to high pressure, is then sent to the generator. Heat is added to the NH_3-H_2O solution under high pressure. This heat energy is usually provided by a boiler or a source such as solar energy. During this process, ammonia is separated from the water solution and ammonia vapor emerges. Water remains in the generator. The ammonia vapor leaving the generator goes to the condenser. Here, the vapor is condensed with the help of cooling water or air and turned into liquid. During condensation, ammonia vapor releases heat to the environment. This stage is when the system operates in heating mode. The condensed liquid ammonia is sent to the evaporator by reducing its pressure through the expansion valve. In the meantime, the pressure and temperature of the ammonia decrease. The low-pressure ammonia liquid evaporates again by taking heat from the environment in the evaporator. The ammonia vapor absorbs heat from the low-temperature environment and cools the environment. During this process, the vapor performs the cooling process of the evaporator by absorbing the heat from the environment. The vaporized ammonia returns to the absorber and the cycle starts again. In this system, a heat source is used instead of a compressor and the absorption/desorption processes of the water-ammonia solution take place. NH_3-H_2O absorption heat pumps offer an efficient heating and cooling solution with low energy consumption and are more environmentally friendly than fossil fuel systems.

3.3. Comparison with Other Energy Systems

NH_3-H_2O absorption heat pumps offer an important option in terms of energy efficiency and environmental sustainability. However, when compared to different heating and cooling systems, a detailed analysis is required to determine which system is more advantageous. Below is an evaluation comparing the NH_3-H_2O absorption heat pump with other energy systems (such as electric heat pumps and fossil fuel systems).

Electric heat pumps are systems that transfer heat from the air or ground to the interior. They perform cooling or heating processes using electrical energy. Their COP values usually range from 3 to 4, meaning they produce 3 to 4 units of heat for each unit of electrical energy. They are compatible with high efficiency, low operating costs and environmentally friendly energy sources. The high electricity costs and the reduced efficiency of electric heat pumps in some regions reduce their effectiveness in the winter months when the outdoor temperature is low.

Fossil fuel systems generate heat using fuels such as natural gas, diesel or coal. Generally, these systems generate energy through combustion. They usually offer efficiency between 70-90%; but this varies depending on the type of fuel used and the type of system. Low initial costs and high heat generation capacity. Carbon emissions and environmental impacts, depletion of fossil fuels, fluctuating fuel costs.

3.4. Thermodynamic calculations and their assumption

The thermodynamic analysis was made with the EES software (Engineering Equation Solver) [25]. Since the NH_3-H_2O absorption heat pump is a thermal system, the COP value is calculated by the formula:

$$\text{COP}=\frac{\text{Cooling or Heating Power Generated}}{\textit{Energy Used in Input (Heat)}} \quad [1]$$

This system absorbs heat at low temperature in the evaporator and receives energy from a heat source. COP values typically depend on temperature differences and the properties of the fluid used in the system. When calculating COP values at different temperatures:

- Evaporator temperature (low temperature) is the part where absorption occurs.
- Condenser temperature (high temperature) is the condensing temperature.
- COP varies depending on the efficiency of the heat energy at the inlet and the behavior of the fluid in the cycle.

Absorption systems at low temperatures usually have lower COP values because the temperature difference between the evaporation and condensation processes is small.

Electric heat pumps transfer heat from the external environment using a mechanical cycle. COP is usually calculated as follows:

$$\text{COP}=\frac{\text{Transferred Heat}}{\textit{Electrical Energy Consumed}} \quad [2]$$

The COP value changes depending on the outside temperature. As the outside temperature increases, the COP value of an electric heat pump increases because the system works more efficiently as the temperature difference decreases. Electric heat pumps use the heat they receive from the outside environment to heat or cool, and therefore their efficiency increases as the ambient temperature increases.

Fossil fuel systems usually work with a boiler or combustion system. Efficiency is calculated with the following formula:

$$\text{Efficiency(\%)}=\frac{\textit{Output Power (Heat or Energy)}}{\textit{Input Energy (Fuel Energy)}}\text{X100} \quad [3]$$

In fossil fuel systems, efficiency is calculated by factors such as combustion efficiency and boiler efficiency, and usually varies between 80% and 95%. These systems depend on the type of fuel and combustion efficiency rather than the outside temperature.

The values in the table are generally calculated using experimental data or standard COP and efficiency values in the literature. The operating performance of the relevant systems under temperature conditions has been determined by simulations. The general methods used for each system are summarized below:

- Absorption Heat Pump: COP values are calculated together with the evaporator, condenser and absorber temperatures. It is found using the cooling load and the thermal energy entering the system.
- Electric Heat Pump: COP is calculated based on the thermal energy transferred according to the electrical energy consumed.
- Fossil Fuel System: Efficiency is calculated by taking into account combustion efficiency and thermal losses.

As a result, the COP or efficiency value of each system is directly related to how the system operates and in which temperature range it is evaluated.

4. Findings

Table 1. Thermodynamic data of NH_3-H_2O absorption heat pump

Parameter	Value	Parameter	Value
T_evaporator [°C]	-5	Mass flow rate (m_dot) [kg/s]	0.05
P_evaporator [bar]	2	T_generator [°C]	120
x_evaporator	1	P_generator [bar]	10
T_condenser [°C]	35	Q_evaporator [kJ/s]	54.53
P_condenser [bar]	10	Q_generator [kJ/s]	68.32
x_condenser	0	COP	0.7981

Table 1 shows the thermodynamic data of the NH_3-H_2O absorption heat pump. The evaporator temperature (T_evaporator) was determined as -5°C, the evaporator pressure (P_evaporator) was 2 bar, and the steam quality at the evaporator outlet (x_evaporator) was determined as 1. The condenser temperature (T_condenser) was recorded as 35°C, the condenser pressure (P_condenser) as 10 bar and the steam quality at the condenser outlet (x_condenser) as 0. The generator temperature (T_generator) is 120°C, the generator pressure (P_generator) is 10 bar, the mass flow rate (ṁ) is 0.05 kg/s, the amount of heat taken from the evaporator (Q_evaporator) is 54.53 kJ/s and the amount of heat taken from the generator (Q_generator) is 68.32 kJ/s. The performance coefficient (COP) of the system was calculated as 0.7981.

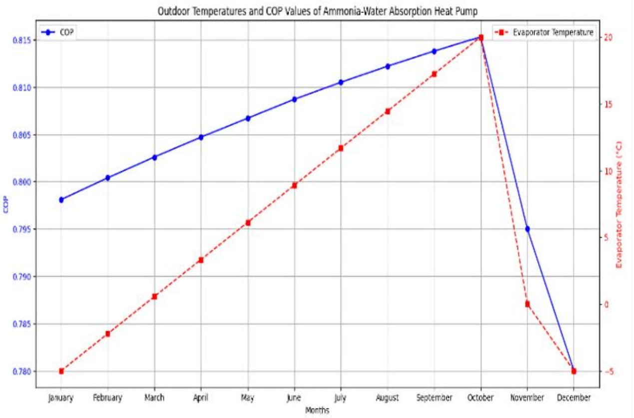

Figure 3. Effect of outdoor temperatures on COP in absorption system

Figure 3 shows the seasonal temperature data of the cooling system and the graphs showing the performance of an absorption heat pump. The data and detailed explanations of the graphs are given below: It represents 12 months of the year from January to December. It is the average outdoor temperature of a city located in a temperate climate zone like Turkey by month. For example, while the average temperature in January is 1.8°C, it is 23.5°C in July. The temperatures in the evaporator section of the absorption heat pump are calculated according to these data and outdoor temperatures. These temperatures vary between -5°C and 20°C. Lower values are seen in the winter months and higher values are seen in the summer months. It represents the coefficient of performance of the heat pump. The COP value varies between 0.7800 and 0.8153 and these values show the efficiency of the heat pump. The higher the COP, the more efficient the system is. The blue line shows the COP values by month in the graph. In January, the COP is 0.7981, while this value increases in the summer months, reaching 0.8138 in September, and then decreases again. The red dashed line shows the evaporator temperatures. This temperature starts at -5°C in January and increases in the summer months, reaching 17.22°C in September.

COP values vary seasonally. As outdoor temperatures increase in the summer months, the COP also tends to increase, indicating that the efficiency of the heat pump varies with the season. The evaporator temperature is directly related to the outdoor temperatures. As the ambient temperatures increase, the evaporator temperatures also increase. This graph can be used to analyze the seasonal performance of absorption heat pumps and helps us visually understand in which seasons the system is more efficient.

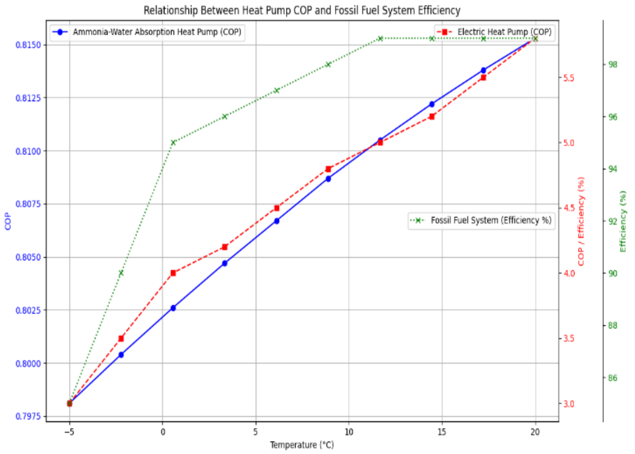

Figure 4. The relationship between heat pump COP and Fossil fuel system efficiency

Figure 4 investigates the coefficients of performance (COP) and efficiency of NH_3-H_2O absorption heat pump, electric heat pump and fossil fuel systems depending on certain temperature values. The numerical data used are summarized below: At temperature -5 °C, the COP of the NH_3-H_2O absorption heat pump is 0.7981, the COP of the electric heat pump is 3.0 and the efficiency of the fossil fuel system is 85%. At temperature -2.222 °C, the COP of the NH_3-H_2O absorption heat pump is 0.8004, the COP of the electric heat pump is 3.5 and the efficiency of the fossil fuel system has increased to 90%. At 0.5556 °C, the COP of the NH_3-H_2O absorption heat pump is 0.8026, the COP of the electric heat pump is 4.0 and the efficiency of the fossil fuel system is 95%. At 3,333 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8047, the COP of the electric heat pump was 4.2, and the efficiency of the fossil fuel system was 96%. When the temperature was 6,111 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8067, the COP of the electric heat pump was 4.5, and the efficiency of the fossil fuel system was 97%. At 8,889 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8087, the COP of the electric heat pump was 4.8, and the efficiency of the fossil fuel system was 98%. At 11.67 °C, the COP of the ammonia-water absorption heat pump was 0.8105, the COP of the electric heat pump was 5.0, and the efficiency of the fossil fuel system reached 99%. At 14.44 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8122, the COP of the electric heat pump was 5.2, and the efficiency of the fossil fuel system was 99%. At 17.22 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8138, the COP of the electric heat pump was 5.5, and the efficiency of the fossil fuel system was 99%. Finally, at 20 °C, the COP of the NH_3-H_2O absorption heat pump was 0.8153, the COP of the electric heat pump was 5.8, and the efficiency of the fossil fuel system reached 99%. The obtained data show that as the temperature increases, the COP of the NH_3-H_2O absorption heat pump increases from 0.7981 to 0.8153, and the COP of the electric heat pump ranges from 3.0 to 5.8. In addition, the efficiency of the fossil fuel system increases from 85% to 99%. These numerical data clearly show the temperature-dependent performance of each system and enable comparisons between energy systems.

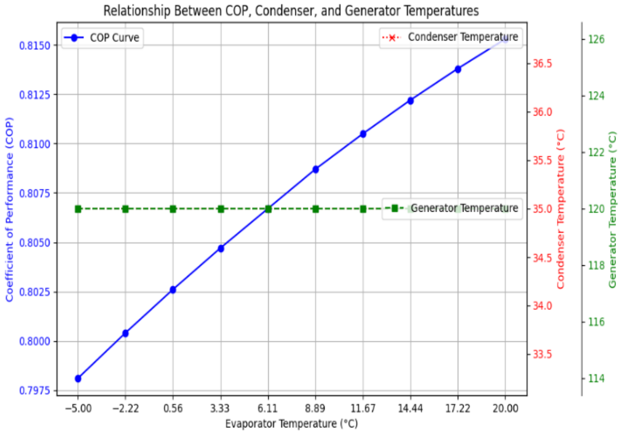

Figure 5. Relationship between COP, condenser temperature, evaporator temperature and generator temperature

Figure 5 visualizes the relationship between Coefficient of Performance (COP), condenser temperature, evaporator temperature, and generator temperature. The data is organized in a dictionary format that includes: A set of coefficients of performance ranging from 0.7981 to 0.8153. A fixed temperature for the condenser of 35 °C. A set of evaporator temperatures ranging from -5 °C to 20 °C. A fixed generator temperature of 120 °C. A blue line and circular markers for COP. A red dotted line and x markers for condenser temperature. A green dashed line and square markers for generator temperature. The graph is appropriately labeled, with axis labels and a title. There is also a legend indicating which line corresponds to which parameter. The grid feature is enabled and the graph size is set to 10 x 6 inches for improved readability. This visualization helps to understand how COP varies with changes in evaporator temperature, together with fixed condenser and generator temperatures. The obtained COP values generally show similar performance when compared to the studies in the literature, but there are some differences. For example, in January, when the outdoor temperature is 1.8°C and the evaporator temperature is -5°C, the COP value is calculated as 0.7981. This value is higher than the COP value of 0.7 obtained in the study of Aman et al. (2014) when the evaporator temperature is 5°C and the condenser temperature is 30°C. This situation shows that the NH_3-H_2O absorption heat pump in your study offers acceptable performance even at low temperatures. In the summer, in July, when the outdoor temperature is 23.5°C and the evaporator temperature is 11.67°C, the COP value is found as 0.8105. This result is similar to the COP value of 0.8105 obtained in the study of Aprile et al. (2016) study, it is lower than the COP value of 1.2 obtained at 15°C evaporator temperature and 40°C condenser temperature. This difference shows that condenser temperatures have a significant effect on system performance. In addition, in the study of Dehghan et al. (2020), the highest COP value of the gas-fired absorption heat pump system was determined as 1.5 when the evaporator temperature was 10°C and the condenser temperature was 35°C. It is quite high compared to the highest COP value of 0.8138 obtained in this article. This difference may be due to the different characteristics of the systems used and indicates that additional studies should be conducted for the optimization of the system.

In general, the ammonia-water absorption heat pump system exhibits competitive performance compared to other studies in the literature at low temperatures, but the COP values at high temperatures are slightly lower compared to the literature.

5. Conclusions

In this study conducted for Isparta province, the performance of the ammonia-water absorption heat pump was analyzed depending on the outdoor temperatures. The effect of seasonal temperature changes on the system efficiency was examined through coefficient of performance (COP) and evaporator temperatures.

In January, when the outdoor temperature was 1.8°C, the evaporator temperature was determined as -5°C and the system COP value was measured as 0.7981. In the summer months, especially in July, the outdoor temperature increased to 23.5°C, while the evaporator temperature reached 11.67°C and the system COP value increased to 0.8105. The highest efficiency was seen in September, when the outdoor temperature was 18.9°C, the COP value was recorded as 0.8138.

These data show that the ammonia-water absorption heat pump operates with lower efficiency at low temperatures, but the system performance improves significantly as the temperature increases. It was observed that the system operates more efficiently, especially in the summer months. As a result, ammonia-water absorption heat pumps were evaluated as a heating solution suitable for the variable climatic conditions of Isparta and were shown to have significant potential in terms of local energy efficiency.

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