

Performance Study of a NH₃/LiNO₃ Absorption Chiller Under South Algerian Climate

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Abstract: This study investigates the feasibility of implementing an NH₃/LiNO₃ absorption chiller under the climatic conditions of Bechar, Algeria. Using energy and exergy analysis techniques, the research evaluates the system's performance under various operating conditions. The absorption cycle is modeled using Engineering Equation Solver (EES) to assess the impact of key parameters on the coefficient of performance (COP). Results indicate that the COP is significantly influenced by generator, condenser, and absorber temperatures. The COP increases from 0.10 to 0.524 as the generator inlet heating water temperature rises, and from 0.10 to 0.628 with increasing absorber temperature. However, the COP decreases from 0.58 to 0.31 as the evaporator temperature increases, and from 0.627 to 0.202 with increasing condenser temperature. The study contributes to ongoing efforts to develop sustainable cooling solutions tailored to regions with extreme climates, highlighting the potential of NH₃/LiNO₃ absorption chillers for solar-driven cooling applications in hot and arid environments like southern Algeria.

Keywords: NH₃/LiNO₃ absorption chiller, solar cooling, exergy analysis, energy efficiency, South Algerian climate.

1. Introduction

Solar-driven absorption cooling systems have gained significant attention in recent years as an environmentally friendly alternative to conventional vapor compression systems. The growing interest in these systems is driven by the need for sustainable energy solutions and the potential to reduce electricity consumption in cooling applications. Muneer et al. (2005) highlighted the importance of sustainable solar electricity production, particularly in developing economies like India. The International Energy Agency has also recognized the potential of solar energy in meeting global energy demands.

Among the various working fluid pairs, the ammonia/lithium nitrate (NH₃/LiNO₃) mixture has emerged as a promising option for absorption chillers, offering several advantages over traditional pairs like water/lithium bromide (H₂O/LiBr) and ammonia/water (NH₃/H₂O). Jaruwongwittaya and Chen (2010) provided a comprehensive review of renewable energy applications with absorption chillers in Thailand, emphasizing the potential of solar-driven systems. The NH₃/LiNO₃ working pair offers several key benefits:

1. No risk of crystallization when operating at high temperatures in the absorber
2. Suitability for air-cooled systems without the need for cooling towers
3. Elimination of the rectifier requirement, reducing machine weight and cost
4. Ability to operate at lower generator temperatures, making it well-suited for solar thermal applications

These characteristics make $\text{NH}_3/\text{LiNO}_3$ systems particularly attractive for solar-driven cooling applications in hot and arid climates, such as those found in southern Algeria. Balaras et al. (2007) provided an overview of solar air conditioning in Europe, highlighting the growing interest in absorption cooling technologies. Additionally, Djelloul et al. (2013) simulated a solar-driven air conditioning system for a house in the dry and hot climate of Algeria, demonstrating the feasibility of such systems in challenging environments. Chidambaram (2011) reviewed various solar cooling methods and thermal storage options, emphasizing the potential of absorption cooling systems in renewable energy applications. The fundamental principles of absorption chillers and heat pumps were extensively covered by Herold et al. (1996), providing a solid foundation for understanding these systems. Recent studies have focused on optimizing solar absorption cooling systems. Assilzadeh et al. (2005) simulated and optimized a LiBr solar absorption cooling system with evacuated tube collectors, demonstrating the potential for improved performance. Louafi and Draoui (2013) conducted a simulation and optimization study for a solar-driven air conditioning system in Bechar, southern Algeria, further validating the applicability of these systems in hot climates. The present study aims to investigate the feasibility and performance of an $\text{NH}_3/\text{LiNO}_3$ absorption chiller under the climatic conditions of Bechar, Algeria. By employing energy and exergy analyses at different air mass flow rates, this research seeks to contribute to the ongoing efforts to develop efficient and sustainable solar cooling solutions for residential applications in challenging environments.

2. AMMONIA/LITHIUM NITRATE ABSORPTION SYSTEMS

Ammonia/lithium nitrate mixture has been reported as a working pair for absorption refrigeration systems since the half of the twentieth century.

Infante Ferreira (1984) published a new set of equations for the equilibrium properties (P-T-x and h-T-x curves). This working fluid does not present a risk of crystallization when operating at high temperatures in the absorber, thus makes it suitable for dissipating the heat released in the condenser and absorber using air and without cooling tower. This is an advantage compared with the conventional water/lithium bromide technology.

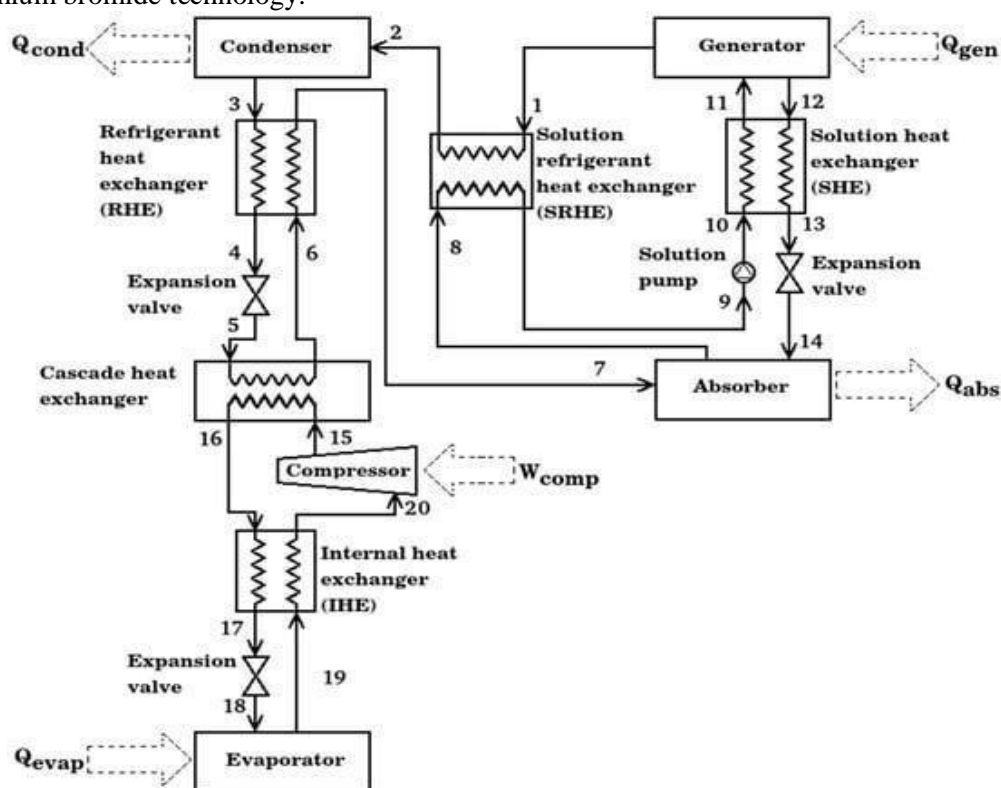


Figure 1 Diagram of an $\text{NH}_3/\text{LiNO}_3$ absorption cycle

3. MODELLING OF THE ABSORPTION CYCLE

The following are the performance equations for each of the components considering continuity (mass balance), the first law of thermodynamics (energy balance) and the second law of thermodynamics (entropy generation).

Global mass: $m_f = m_r - m_p$ (III.1) The fluid mass flow rate :

$$mf * X7 = mr * X3 - mp * X4 \quad (III.2)$$

$$mf * X7 = mr * X3 - (mr - mf) * X4 \quad (III.3) \text{ We define the coefficient of circulation as :}$$

$$Ff = mr/mf = (X7 - X4)/(X3 - X4) \quad (III.4)$$

The concentration is defined by :

$$Xi = (mf/mT) \quad (III.5)$$

$$\text{Condenser: } Qc = mf * (h8 - h7) \quad (III.6)$$

$$\text{Evaporator: } Qe = mf * (h10 - h9) \quad (III.7) \text{ Generator: } Qg = mf * h7 - mr * h3 + mp * h4$$

$$(III.8) \text{ Absorber: } QA = mr * h1 - mf * h10 - mp * h6 \quad (III.9) \text{ The valve 1: } h5 = h6 \quad (III.10)$$

$$\text{The valve 2: } h8 = h9 \quad (III.11) \text{ The pump: } Wp = mr * (h1 - h2) \quad (III.12)$$

Heat exchanger:

$$E = (T4 - T5)/(T4 - T2) = (T3 - T2)/(T4 - T2) \quad (III.13)$$

The coefficient of performance:

$$COP = Qe/(Qg + Wp) \quad (III.14)$$

4. SYSTEM OPTIMISATION

The whole absorption cycle is modelled using engineering equation solver (EES). EES is an acronym for engineering equation solver; solving differential equations and facilitating information output, the entire problem of system simulation reduces to a problem of identifying all the components that comprise the particular system and formulating a general mathematical description of each. EES provides numerical solution of nonlinear algebraic and differential equations. In addition, EES provides built-in thermodynamic and transport property functions for many fluids, including water, dry and moist air, most CFC and HCFC refrigerants, and others. Included in the property database are the thermodynamic properties for lithium bromide/water and ammonia/water mixtures. The combination of a robust nonlinear equation solver and absorption fluid properties makes EES a very powerful tool for analysis and design of absorption systems [7].

In the following, sensitivity analyses and simulations of the different components of the installation are presented in order to improve the efficiency of the system. The behaviour of the complete system is then studied.

5. RESULTS AND DISCUSSION

The analysis of the results obtained from simulations performed with EES software allows evaluating the performance of the NH₃/LiNO₃ absorption system under different operating conditions. The main results are presented below.

Figure 2 shows the evolution of the coefficient of performance (COP) as a function of the inlet temperature of hot water in the generator. We observe that the COP increases rapidly from an initial low value of 0.10 to reach a constant value of 0.524. This trend is explained by the fact that a higher temperature at the generator allows better desorption of the refrigerant, thus improving the overall efficiency of the cycle.

Figure 3 illustrates the effect of varying the absorber temperature on the system's COP. We observe a similar evolution to that observed for the generator, with an increase in COP from 0.10 to a stable value of 0.628. This improvement in performance with increasing absorber temperature can be attributed to better absorption of the refrigerant into the solution.

Figure 4 presents the variation of COP as a function of evaporator temperature. Contrary to previous trends, we observe here a decrease in COP from 0.58 to 0.31 as the evaporator temperature increases. This behavior is explained by the fact that a higher evaporation temperature reduces the temperature difference between the evaporator and the condenser, thus decreasing the efficiency of the refrigeration cycle.

Figure 5 shows the influence of condenser temperature on the system's COP. We observe a significant decrease in COP, from 0.627 to 0.202 as the condenser temperature increases. This drop in performance is due to the increase in condensation pressure, which requires more energy to compress the refrigerant and reduces the overall efficiency of the cycle.

The study reveals that the performance of the NH₃/LiNO₃ absorption system is strongly influenced by the temperatures of different components. The results show that:

1. Increasing generator and absorber temperatures improves the system's COP.
2. Elevating evaporator and condenser temperatures has a negative effect on performance.
3. The generator's heat transfer coefficient has a relatively low impact on COP, with a slight improvement for very low heat transfer values.

These observations highlight the importance of optimizing the system's operating conditions, particularly in the context of the hot and arid climate of southern Algeria. It is crucial to maintain adequate temperatures at the generator and absorber while minimizing evaporator and condenser temperatures to maximize the efficiency of the solar absorption cooling system.

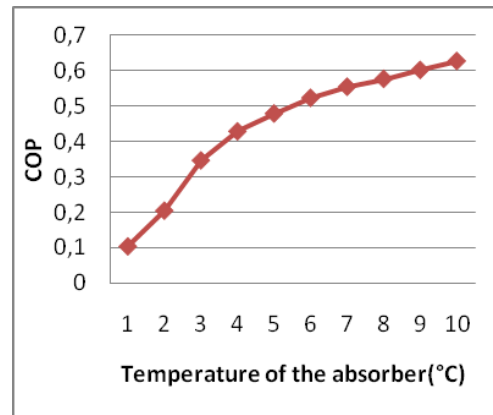
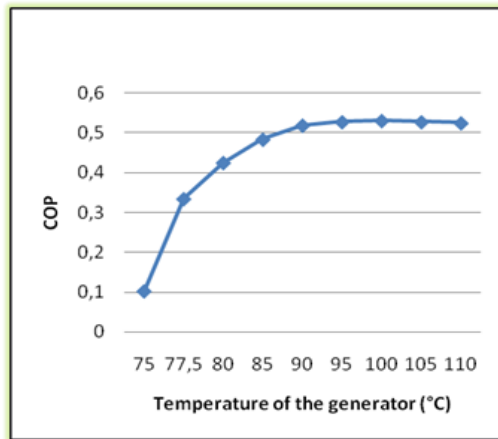


Fig 2. Effect of the variation of the generator T° Fig 3. Effect of the variation of the absorber T°

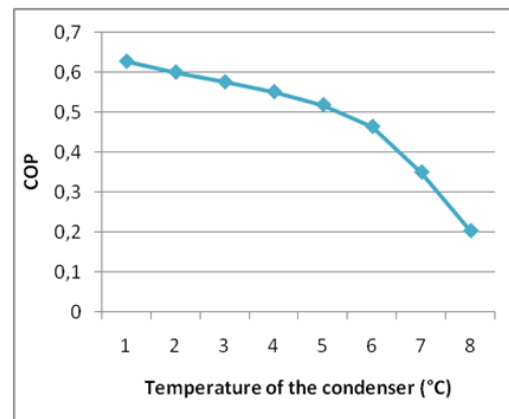
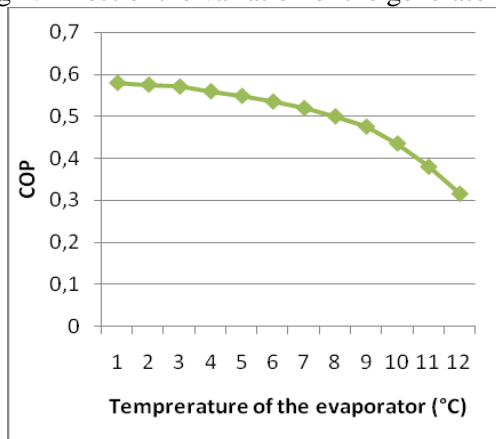


Fig 4. Effect of the variation of the evaporator T° Fig 5. Effect of the variation of the condenser T°

It shows that the evaporator temperature decreases with the source temperature while the generator outlet solution temperature, the generator inlet solution temperature and the condensation temperature increase. The generator inlet temperature and the generator inside heat transfer coefficient could not be increased too much.

6. CONCLUSION

The NH₃/LiNO₃ absorption chiller shows promise for application in the extreme climate of southern Algeria. Its ability to operate at lower generator temperatures, coupled with the region's abundant solar resources, makes it an attractive option for sustainable cooling.

However, careful system design and optimization are necessary to overcome the challenges posed by high ambient temperatures and water scarcity. The study reveals that the system's performance is significantly influenced by generator, condenser, and absorber temperatures. The COP shows varying sensitivities to different operating parameters, with the greatest impacts observed from changes in condenser and evaporator temperatures. Further research and pilot projects are recommended to assess the long-term performance and economic viability of these systems under actual operating conditions in

southern Algeria. Additionally, exploring hybrid systems that combine absorption cooling with other technologies may provide more robust solutions for this challenging environment.

NOMENCLATURE

T: Temperature. V: Volume.

Q: Thermal energy. W_p: Pump power.

E: Efficiency of the heat exchanger. m: Mass flow rate

h: Enthalpy. P: Pressure.

C.O.P: Coefficient of performance. X : the mass fraction.

Subscripts

a : absorber. c : condenser.

e : evaporator.

f : fluid.

g : generator. i : state point. p : pump.

r : rectifier.

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