Comprehensive Journal of Science
Volume (10), Issue (39), (March, 2026)
ISSN: 3014-6266

مجلة العلوم الشاملة
المجلد (10) العدد 39 مارس 2026
ردمد: 3014-6266

THERMODYNAMIC SYNERGY ASSESSMENT OF A DOUBLE-FLASH GEOTHERMAL–LiBr/H_2O ABSORPTION TRIGENERATION CONFIGURATION

Hatem Khalifa Said
Mechanical Engineering
Higher Institute of Science & Technology Azizia / Libya
hattem222@yahoo.com

Ahmed elbarouni hadya
Mechanical Engineering
Higher Institute of Science & Technology Azizia / Libya
hattem222@yahoo.com

تاريخ الاستلام:2026/01/03 –تاريخ المراجعة: 2026/01/23– تاريخ القبول: 2026/01/30– تاريخ للنشر :2026 /02/25

Abstract

This research presents a thermodynamic evaluation of a combined trigeneration system driven by geothermal resources. The configuration integrates a double-flash geothermal power plant with a lithium bromide water (LiBr/H_2O) absorption refrigeration system, enabling the simultaneous production of electricity heat and cooling.

First- and second-law analyses were performed using the Engineering Equation Solver (EES) to characterize system behavior. The system achieved an absorption refrigeration coefficient of performance (COP) of 0.6849 an overall energy efficiency of 16.49%, and an exergy efficiency of 30.85% .

The findings demonstrate the technical feasibility of exploiting geothermal energy for multi output production and highlight areas with high exergy destruction where performance enhancement is needed.

Keywords: *geothermal energy absorption refrigeration-LiBr/H_2O-exergy-energy efficiency.*

ملخص

يقدم هذا البحث تقييمًا ديناميكيًا حراريًا لنظام توليد ثلاثي متكامل يعمل بالطاقة الحرارية الأرضية. يدمج هذا النظام محطة طاقة حرارية أرضية مزدوجة التبخير مع نظام تبريد بالامتصاص باستخدام بروميد الليثيوم والماء (LiBr/H_2O)، مما يتيح إنتاج الكهرباء والحرارة والتبريد في آنٍ واحد.

أُجريت تحليلات القانونين الأول والثاني للديناميكا الحرارية باستخدام برنامج حل المعادلات الهندسية (EES) لتوصيف سلوك النظام. حقق النظام معامل أداء تبريد بالامتصاص (COP) قدره 0.6849، وكفاءة طاقة إجمالية قدرها 16.49%، وكفاءة طاقة متاحة قدرها 30.85%.

تُظهر النتائج الجدوى التقنية لاستغلال الطاقة الحرارية الأرضية لإنتاج متعدد المخرجات، وتُسلط الضوء على المناطق التي تشهد فقدانًا كبيرًا للطاقة المتاحة، حيث يلزم تحسين الأداء.

الكلمات المفتاحية: الطاقة الحرارية الأرضية، امتصاص التبريد، LiBr/H_2O، دورة الطاقة المتاحة، كفاءة الطاقة.

1. Introduction

Geothermal fields provide a naturally available and renewable heat source located deep beneath the Earth's crust. Depending on the temperature of the extracted fluid geothermal energy can be utilized directly for thermal applications or indirectly for power generation and cooling.

Within geothermal electricity production steam separation from geothermal brine is essential prior to turbine expansion to ensure adequate vapor quality and prevent mechanical damage After expansion geothermal brine remains at a temperature that is still suitable for energy recovery through auxiliary thermal systems.

Absorption refrigeration systems represent a promising approach to utilize this remaining heat. In particular the LiBr/H_2O working pair is known for its strong thermodynamic affinity operating at low pressures and enabling cooling using thermal input rather than electrical work. Existing literature includes geothermal-coupled absorption cooling cascaded systems hybrid arrangements, and geothermal-supported hydrogen precooling applications which collectively confirm the suitability of geothermal heat as a driving source.

The present study aims to perform a thermodynamic assessment of a geothermal-powered trigeneration configuration, focusing on the overall system efficiency exergy distribution, and sensitivity of system performance to key parameters including geothermal temperature absorber pressure, and pressure ratios.

2. System Description

The proposed trigeneration architecture (Figure 1) couples a double-flash geothermal power plant with a LiBr/H_2O absorption refrigeration cycle enabling concurrent electrical heating and cooling outputs.

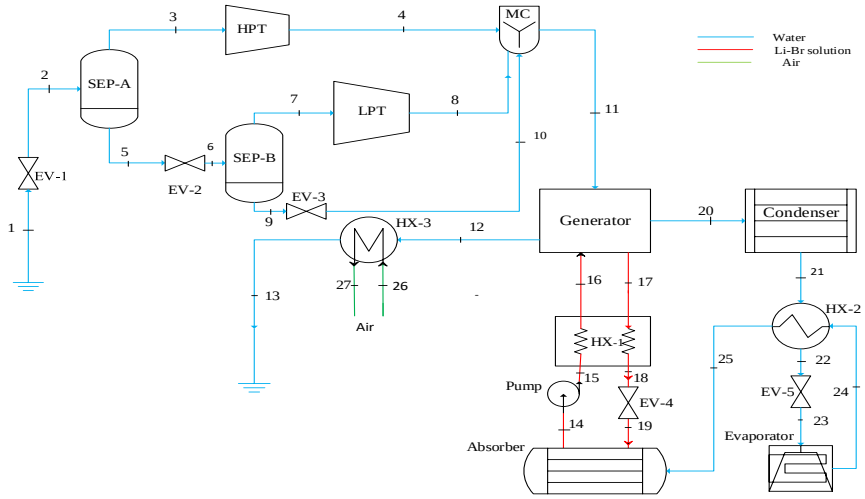

Fig. 1. Schematic diagram of the integrated trigeneration system.

In the geothermal subsystem high-temperature geothermal fluid extracted from production wells undergoes throttling through an expansion valve partially vaporizing the fluid and producing a vapor-liquid mixture.

The vapor fraction enters the high-pressure turbine (HPT) to generate power while the remaining liquid is flashed again to produce low-pressure vapor for the low-pressure turbine (LPT) The brine exiting the final flashing stage-still containing usable thermal energy-is directed through a heat exchanger before reinjection.

The absorption refrigeration subsystem employs the LiBr/H_2O working pair a strong LiBr solution is pumped to higher pressure, preheated using a solution heat exchanger and then directed into the generator where geothermal heat facilitates the desorption of refrigerant vapor the vapor flows to the condenser is liquefied and is expanded through a valve prior to entering the evaporator in which the cooling effect is produced.
The weak solution discharged from the generator is cooled through the solution heat exchanger and directed to the absorber where vapor absorption regenerates the strong solution completing the cycle.

3. Thermodynamic Analysis

The thermodynamic modeling of the system is based on steady-state, steady-flow conservation equations. The general forms applied are as follows:

Mass balance:

$$\Sigma\dot{m}_{in} = \Sigma\dot{m}_{out} \quad (1)$$

Energy balance:

$$\Sigma(\dot{m}h)_{in} - \Sigma(\dot{m}h)_{out} + \dot{Q} - \dot{W} = 0 \quad (2)$$

Exergy balance:

$$\Sigma\dot{E}_{x,in} - \Sigma\dot{E}_{x,out} + \dot{E}_{x,heat} - \dot{W} = \dot{E}_D \quad (3)$$

Exergy transfer by heat:

$$\dot{E}_{x,heat} = \dot{Q}\,(1 - T_0/T) \quad (4)$$

Specific flow exergy:

$$ex = (h - h_0) - T_0(s - s_0) \quad (5)$$

Coefficient of Performance (COP):

$$COP = \dot{Q}_{eva} / (\dot{Q}_{gen} + \dot{W}_{pump}) \quad (6)$$

Overall energy efficiency:

$$\eta_{en} = (\dot{W}_{net} + \dot{Q}_{eva} + \dot{Q}_{heat}) / \dot{Q}_{in} \quad (7)$$

Overall exergy efficiency:

$$\eta_{ex} = (\dot{W}_{net} + \dot{E}_{eva} + \dot{E}_{heat}) / \dot{E}_{in} \quad (8)$$

Engineering Equation Solver (EES) was used to evaluate thermodynamic properties and simulate system performance across varying operating parameters.

4. Results and Discussion

Simulation results indicate that the geothermal-powered trigeneration configuration exhibits measurable performance benefits.
The absorption subsystem yielded a COP of 0.6849 demonstrating efficient cooling generation driven primarily by geothermal heat.
The overall energy efficiency was 16.49% while overall exergy efficiency reached 30.85% confirming the ability of geothermal systems to supply multiple useful energy forms.

Exergy destruction analy٧sis (Figure 2) showed that the absorber contributed the highest irreversibility within the LiBr/H_2O cycle followed by the evaporator and generator. These losses arise from temperature gradients mass transfer irreversibilities and mixing effects.
Therefore absorber design improvements-including enhanced heat transfer surfaces and improved solution flow distribution-may significantly increase performance.

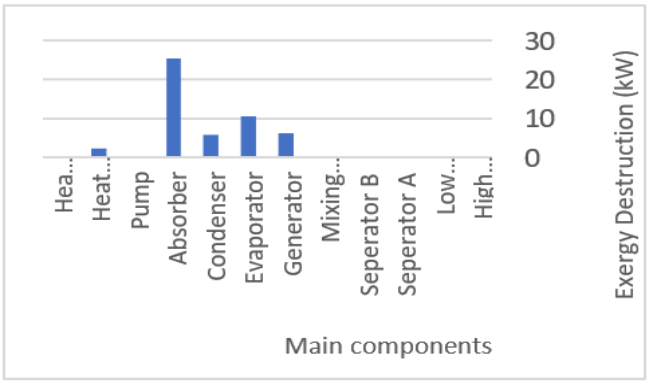

Fig. 2. Exergy destruction values for the main components of the system.

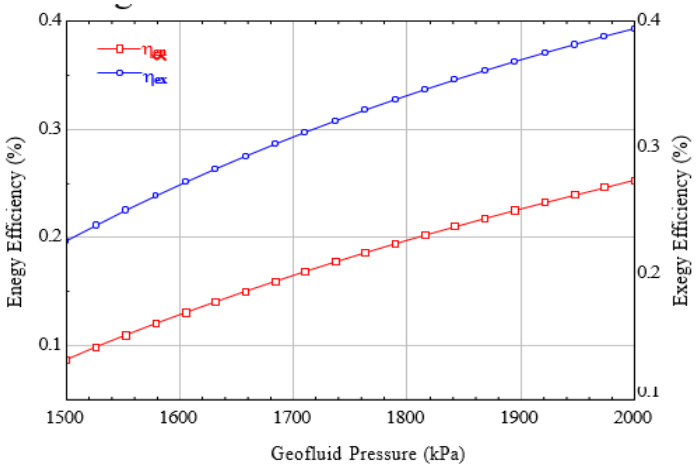

Fig. 3. Effect of geothermal fluid pressure on energy and exergy efficiencies.

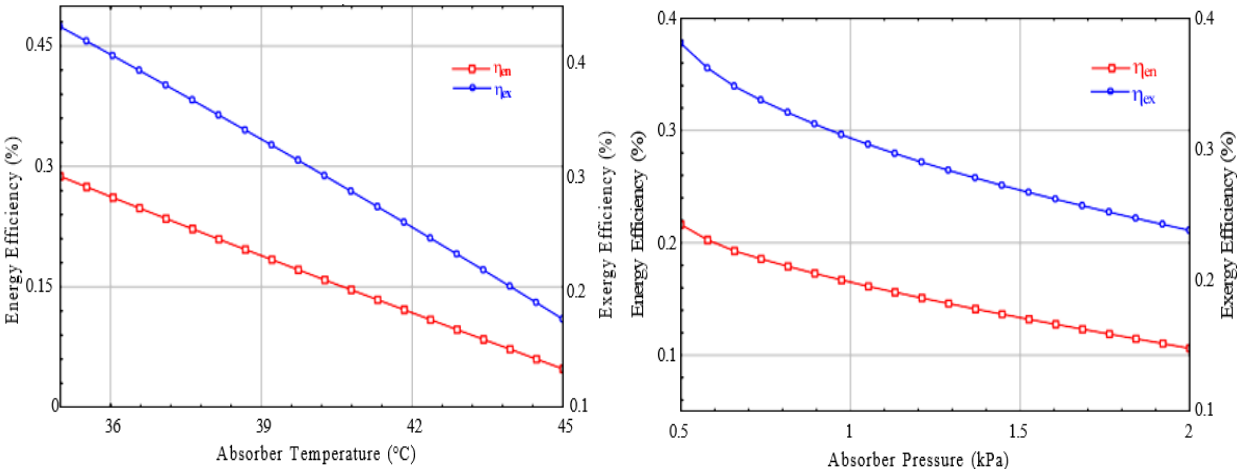

Fig. 4. Effects of absorber outlet pressure and absorber outlet temperature on system efficiencies.

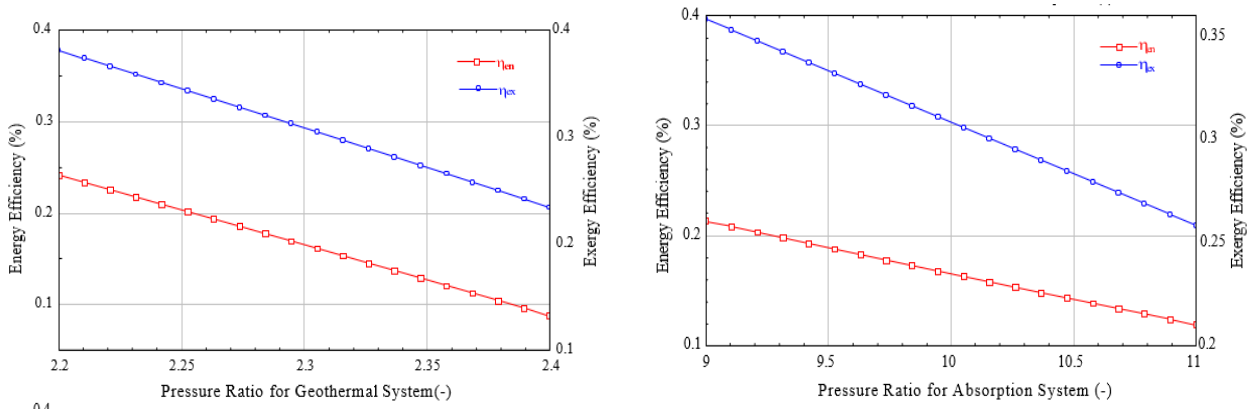

Fig. 5. Effect of geothermal and absorption system pressure ratios on energy and exergy efficiencies.

Parametric analysis (Figures 3–5) illustrates that increasing geothermal fluid pressure induces performance improvement due to increased available thermal energy.
Conversely higher absorber pressure or elevated absorber outlet temperature lead to reduced efficiencies because the thermodynamic driving forces for desorption diminish. Sensitivity results showed that when absorber outlet pressure rises from 0.5 kPa to 2 kPa energy efficiency declines from 21.16% to 10.6% and exergy efficiency drops from 38.06% to 23.8%. (Table 1) summarizes key output variables of the system:

Table (1) The most important parameters gained from system analysis.

Description	**Value**
High Pressure Turbine Power (kW)	23.14
Low Pressure Turbine Power (kW)	8.337
Pump Power (kW)	0.00548
Overall Energy Efficiency (%)	16.49
Overall Exergy Efficiency (%)	30.85
COP (-)	0.6849
Generator heat transfer rate (kW)	127.3
Evaporator heat input rate (kW)	87.21
Net power output of integration system (kW)	31.47
Heat exchanger I heat transfer rate (kW)	66.15
Heat exchanger II heat transfer rate (kW)	1.823
Heat exchanger III heat transfer rate (kW)	25.13
Condenser heat rejection rate (kW)	88.31
Heat output value (kW)	25.13

Fig 6. shows variations in the overall energy and exergy efficiencies, versus the temperature of air entering the heat exchanger.

It's clear that when the temperature rises from 10°C to 40°C overall energy efficiency decreases slightly from approximately 31.53% to 30.16 %

While the exergy efficiency value drops significantly from 18.22% to 14.76%.

Fig 7. Shows the relation between heat exchangers effectiveness and overall efficiencies of the system.

Energy efficiency is increased slightly from 16.36% to 16.63% by the increment of heat exchangers effectiveness from 50% to 90% and exergy efficiency rate shows a rise from 30.7% to 31% at same heat exchangers effectiveness rate.

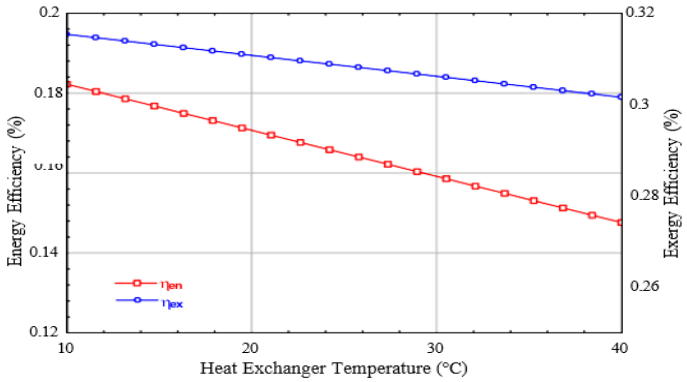

Fig. 6. Effect of air temperature entering the heat exchanger on system efficiencies.

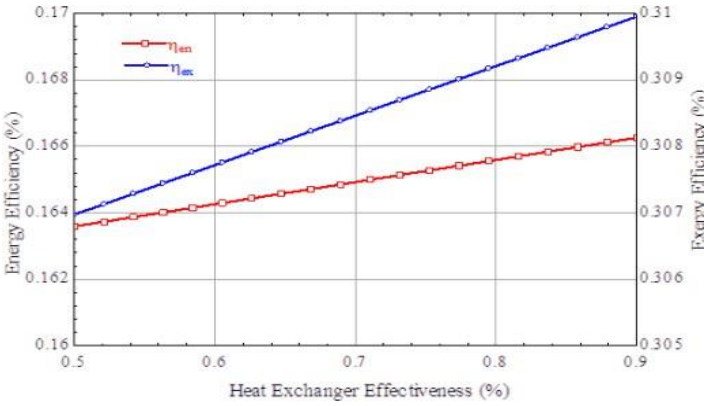

Fig. 7. Effect of heat exchanger effectiveness on energy and exergy efficiencies.

Heat exchanger effectiveness demonstrates a moderate positive impact, underscoring the importance of high-quality recuperative components in absorption-based systems.

Fig. 8 shows the effect of ambient temperature on overall efficiencies of the system. Therefore ambient temperature plays a notable role particularly affecting exergy efficiency more strongly than energy efficiency.

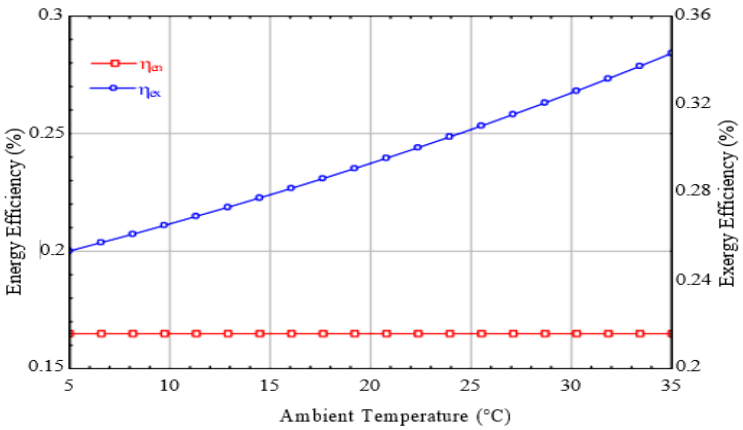

Fig. 8. Effect of ambient temperature on energy and exergy efficiencies

5. Conclusion

This work investigated a geothermal-driven trigeneration system combining a double-flash geothermal power plant and a LiBr/H_2O absorption cycle.

The system produced a net electrical output of 31.47 kW- a COP of 0.6849 and overall efficiencies of 16.49% (energy) and 30.85% (exergy) confirming the system's feasibility for sustainable multi-energy generation.

Exergy destruction results indicate that the absorber is the most critical element requiring optimization, followed by the evaporator and generator.

Future performance improvements can be obtained through enhanced heat exchanger design, flow-rate optimization, and advanced absorber configurations.

Overall the study demonstrates that geothermal-based trigeneration offers a reliable, renewable solution for simultaneous heating cooling, and power generation especially in regions with available geothermal resources.

References

1. Tesha. (2009). Absorption Refrigeration System as an Integrated Condenser Cooling Unit in a Geothermal Power Plant. United Nations University, Geothermal Training Programme.
2. Lech, P. (2009). A New Geothermal Cooling–Heating System for Buildings (Doctoral dissertation, Master's Thesis. University of Iceland and the University of Akureyri).
3. Kanoglu, M., Yilmaz, C., & Abusoglu, A. (2016). Geothermal energy use in absorption precooling for Claude hydrogen liquefaction cycle. International Journal of Hydrogen Energy, 41(26), 11185-11200.
4. Uwera, J., Itoi, R., Jalilinasrabady, S., Jóhannesson, T., & Benediktsson, D. Ö. Design of a Cooling System Using Geothermal Energy for Storage of Agricultural Products with Emphasis on Irish Potatoes in Rwanda, Africa.
5. Kairouani, L., & Nehdi, E. (2006). Cooling performance and energy saving of a compression–absorption refrigeration system assisted by geothermal energy. Applied thermal engineering, 26(2), 288-294.
6. Best, R., Heard, C. L., Fernandez, H., & Siqueiros, J. (1986). Developments in geothermal energy in Mexico—Part five: The commissioning of an ammonia/water absorption cooler

operating on low enthalpy geothermal energy. Journal of heat recovery systems, 6(3), 209-216.
7. Ishida, T., Kawano, S., Kohtaka, I., Yamada, K., Kaku, H., & Narita, T. (1991). U.S. Patent No. 5,007,240. Washington, DC: U.S. Patent and Trademark Office.
8. Ishida, T., Kawano, S., Kohtaka, I., Yamada, K., Kaku, H., & Narita, T. (1989). Hybrid Rankine cycle system U.S. Patent No. 5,007,240. Washington, DC: U.S. Patent and Trademark Office.
9. Shokati, N., Ranjbar, F., & Yari, M. (2014). A comparative analysis of rankine and absorption power cycles from exergoeconomic viewpoint. Energy Conversion and management, 88, 657-668.
10. Novotny, V., & Kolovratnik, M. (2016). Absorption power cycles for low-temperature heat sources using aqueous salt solutions as working fluids. International Journal of Energy Research.
11. Wu, C. (1992). Cooling capacity optimization of a geothermal absorption refrigeration cycle. International journal of ambient energy, 13(3), 133-138.
12. Nowak, W., Stachel, A. A., & Borsukiewicz-Gozdur, A. (2008). Possibilities of implementation of absorption heat pump in realization of the Clausius–Rankine cycle in geothermal power station. Applied Thermal Engineering, 28(4), 335-340.
13. Lund, J. W. (1996). Lectures on direct utilization of geothermal energy. United Nations University Geothermal Training Programme.
14. Hultén, M., & Berntsson, T. (2002). The compression/absorption heat pump cycle—conceptual design improvements and comparisons with the compression cycle. international Journal of Refrigeration, 25(4), 487-497.
15. Ratlamwala, T. A. H., Dincer, I., & Gadalla, M. A. (2012). Thermodynamic analysis of a novel integrated geothermal based power generation-quadruple effect absorption cooling-hydrogen liquefaction system. international journal of hydrogen energy, 37(7), 5840-5849.
16. Rafferty, K. (1984). Absorption refrigeration: cooling with hot water. Geotherm. Energy Mag.;(United States), 12(3).
17. Klein, S. A. (2009). Engineering Equation Solver for Microsoft Windows Operating Systems: Commercial and Professional Versions. F-Chart Software, Madison, WI, available at: http://www. fchart. com/assets/downloads/ees_manual. pdf.
18. Cengel, Y. A., & Boles, M. A. (2002). Thermodynamics: an engineering approach. Sea, 1000, 8862.
19. Ozturk M, Dincer I (2013). Thermodynamic analysis of a solar-based multi-generation system with hydrogen production. Appl Therm Eng 51(1-2);1235-1244
20. Ozturk M, Dincer I (2013). Thermodynamic assessment of an integrated solar power tower and coal gasification system for multi-generation purposes. Energy Conversion Manage 76;1061-1072