



HAL
open science

Transient exergy analysis of ejector cooling and thermoelectric generator systems using heat storage and parabolic trough collector for residential buildings

T Gholizadeh Baris, H Ghiasirad, K Megdouli, S Anvari, B Stanek, A Skorek-Osikowska, L Bartela

► To cite this version:

T Gholizadeh Baris, H Ghiasirad, K Megdouli, S Anvari, B Stanek, et al.. Transient exergy analysis of ejector cooling and thermoelectric generator systems using heat storage and parabolic trough collector for residential buildings. CISBAT 2023, Sep 2023, Fribourg, Swaziland. 10.1088/1742-6596/2600/6/062009 . hal-04334117

HAL Id: hal-04334117

<https://hal.science/hal-04334117v1>

Submitted on 10 Dec 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

PAPER • OPEN ACCESS

Transient exergy analysis of ejector cooling and thermoelectric generator systems using heat storage and parabolic trough collector for residential buildings

To cite this article: T Gholizadeh Baris *et al* 2023 *J. Phys.: Conf. Ser.* **2600** 062009

View the [article online](#) for updates and enhancements.



245th ECS Meeting • May 26-30, 2024 • San Francisco, CA

Submit now!

Don't miss your chance to present!

Connect with the leading electrochemical and solid-state science network!

Deadline Extended: December 15, 2023



Transient exergy analysis of ejector cooling and thermoelectric generator systems using heat storage and parabolic trough collector for residential buildings

T Gholizadeh Baris¹, H Ghiasirad^{1,*}, K Megdoui², S Anvari³, B Stanek¹, A Skorek-Osikowska¹ and L Bartela¹

¹ Silesian University of Technology, Department of Power Engineering and Turbomachinery, Gliwice, Poland

² Institute Jean Le Rond d'Alembert, Sorbonne Université, Faculté des Sciences et Ingénierie. Campus Pierre et Marie Curie 75252 Paris, France

³ Department of Electrical Engineering, University of Jaèn, 23700, EPS Linares, Jaèn, Spain

* Corresponding author: hamed.ghiasirad@polsl.pl

Abstract. The large amount of energy consumption has attracted the attention to exploiting renewable energy sources, the most significant of which are solar energy applications in hot climates to meet the demands of cooling and power. The novelty of the present study lies in applying transient exergy analysis to two ejectors and two evaporators in an ejector cooling cycle. Furthermore, the study uses solar data specific to Tehran in Iran. Third, by absorbing waste heat from the hot parts of the condenser, the thermoelectric generator system provides the energy needed to run the pumping and electrical control systems, thereby creating a fully autonomous system. Thermodynamic model have been designed using EES software. The results of Sandia National Laboratory (SNL) and the National Renewable Energy Laboratory (NREL) have validated the parabolic trough solar model. The comparison with the experimental data collected by SNL during the LS-2 tests on the AZTRAK platform has shown good agreement. Weather conditions were analyzed as transients using Meteororm software. The results show that the solar system produced the most heat in June and the least in December, with 816 kW and 262.3 kW, respectively. Additionally, production power and cooling in June are 5.9 kW and 86 kW, and in December: 2.7 kW and 28 kW. Regarding exergy destruction percentages, the solar collector has 86% and the storage tank has 6.5%.

Keywords: Parabolic trough collector; Thermal energy storage; Ejector cooling cycle; Exergy analysis; Dynamic study

1. Introduction

Iran uses several sources to produce its energy, such as nuclear, oil, natural gas, biomass, solar, etc., with proportions that vary from year to year. This is what is known as the energy mix. Renewable energies (RE) are powered by the sun, wind, the heat of the earth, waterfalls, tides, etc. These sources of energy, considered inexhaustible on the human time scale, do not generate waste or polluting emissions. Renewable energy is important for the climate, for health, our economy, and for our independence. For the climate: Renewable energies allow us to reduce our greenhouse gas emissions to meet the climate emergency for health: the transformation of our energy production will have health effects for our economy: the more renewable energies are developed, the more their price drops. The development of solar refrigerators has been one of the main areas of applied research in recent years. According to the International Institute of Refrigeration, air conditioning and refrigeration applications account for 10-20% of the total electrical energy produced in the world [1].



The objective of this article is to propose an alternative and clean solution to generate cold. We have created a self-contained, reliable, and flexible system that uses the direct conversion of solar thermal energy into cold. Iran's climate favors the use of these systems, since it has a good solar potential. There are many studies in the literature that examine solar refrigeration systems, and more specifically solar refrigeration systems with ejectors, that have become competitive with other technologies (absorption, adsorption, etc.) because of their lower cost and simplicity. Pollerberg et al. [2] have experimentally studied a solar-driven steam jet ejector chiller with a cooling capacity of 1 kW. They concluded that COP increases with decreasing condenser temperature. Vidal et al. [3] performed a thermoeconomic optimization of the combined ejector/vapor compression system assisted by solar energy. They found the COP value of the system equal to 0.89 for a cooling capacity of 10.5 kW. Bellos et al. [4] studied the energy and exergy performance of a new solar-powered refrigeration system powered by evacuated tube collectors and uses R141b as a refrigerant. Their results clearly showed that the suggested system performs better than a conventional ejector refrigeration system. Salimpour et al. [5] performed an exergoeconomic analysis of four solar-driven steam ejector refrigeration systems. The objective of their study was to thoroughly compare and discuss the characteristics of each configuration to find the most efficient system. A novel solar-driven multi-ejector refrigeration system with an internal heat exchanger is proposed and studied by Beyrami and Hakkaki-Fard [6]. The results showed that the proposed new system can provide up to 94% of the required cooling load for the building. Xu et al. [7] performed an energy comparison and an advanced exergetic analysis for a novel solar-driven ejector-compression refrigeration system. The results of the analysis show that the COP increased by 20.6% and its total annual cost was reduced by 7.8%, compared to the traditional ejector compressor cycle.

2. Description of the proposed cycle

Figure 1 shows a schematic of the proposed system. There are four parts to the proposed system: a solar collector field, a heat storage tank, an ejector cooling cycle with two evaporators, and a thermoelectric generator (TEG) unit. In general, the system functions as follows: Solar energy is absorbed in the collector loop as heat and transferred to the circulating fluid in the storage tank. The collecting fluid then transmits the heat to the working fluid of the new refrigeration system to produce cooling and power for users, and then returns to the collector. Also note that the storage tank provides the necessary energy to run the refrigeration system during off-peak times (at night). The working fluid receives heat from the heater, leading to vaporization of states 1 and 9. Subsequently, a secondary fluid is ejected from the evaporator (states 2 and 10). Through the primary nozzle, the working fluid under pressure enters the manifold, passes through the manifold, and drives the secondary fluid from the evaporator. The two fluids then enter the second nozzle, where, after mixing, they are compressed in the diffuser until the pressure of the TEG. A TEG unit is used instead of a conventional condenser for cooling state 12. It also generates electricity. The condensation and generation of power occur at a constant temperature. After leaving the TEG (state 13), the liquid splits into two streams (states 4 and 14). The streams go through the expansion valves (states 5 and 15), then evaporators so that cooling capacities can be provided at two different temperatures (5 °C and -5 °C). The other streams enter the pumps (states 7 and 17) to be compressed and circulated to the heaters (states 8 and 18).

3. Materials and Methods

3.1. Thermodynamic assumptions

Based on some assumptions, a solar-energy-powered power and cooling system is simulated using the EES software [8]. According to these assumptions, the system operates in control volume, ignores potential and kinetic energy changes, isenthalpic conditions are assumed prior to and after the expansion valve, the evaporator and condenser outlets are saturated, and chemical exergy is not experienced by the work fluids. Table 1 includes a list of the main input data for the proposed cycle modeling. All the input data and methodology of solar collector and heat storage are collected from Ref. [9,10].

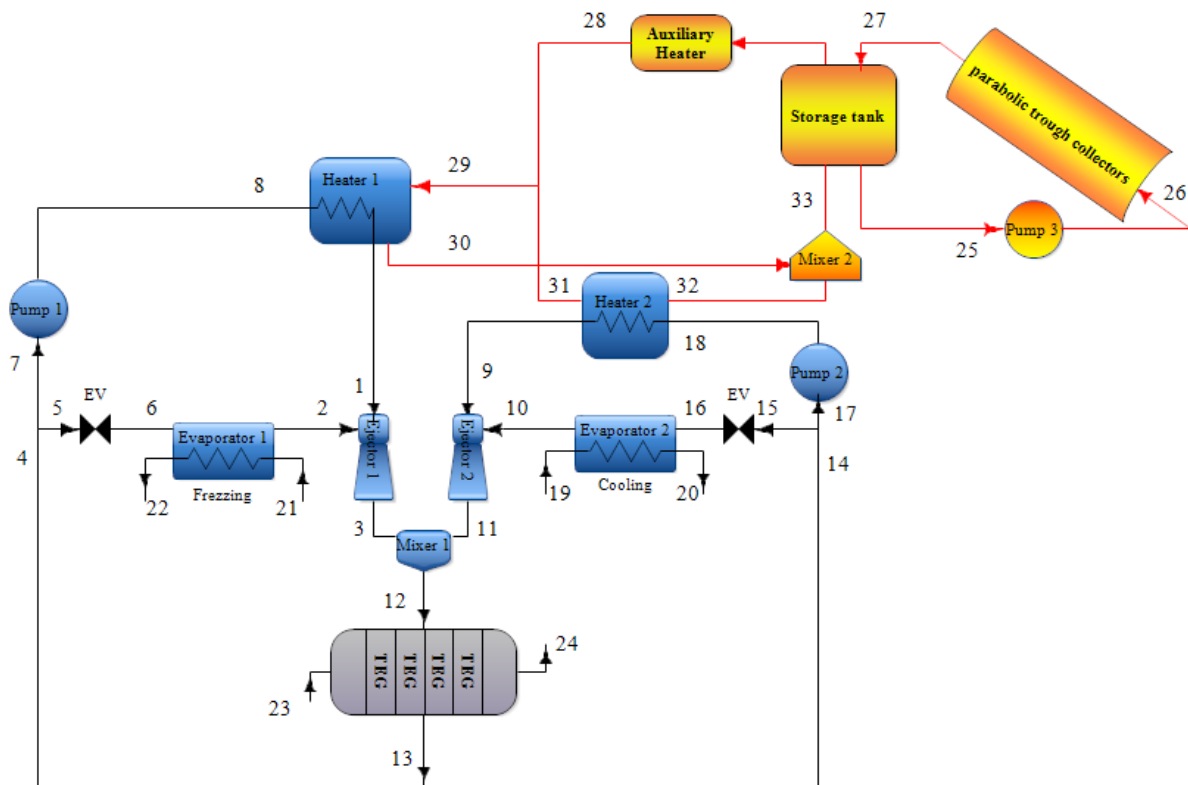


Figure 1. Schematic diagram of the proposed cooling and power cycle

Table 1. Input parameters for the thermodynamic simulation of the proposed system.

Parameter	Value	Ref
Thermal fluid per square meter of collector area (L/m ²)	40	[10]
Wind speed (m/s)	2	[11]
Minimum temperature of stored tank (°C)	150	-
Reference pressure, P_0 (kPa)	101.3	[12]
Heater 1 temperature, $T_{heat\ 1}$ (°C)	110	[13,14]
Heater 2 temperature, $T_{heat\ 2}$ (°C)	95	[14]
Evaporator 1 temperature, $T_{eva\ 1}$ (°C)	-5	[14]
Evaporator 2 temperature, $T_{eva\ 2}$ (°C)	5	[14]
The measured TEG efficiencies measured correspond, ZT_m	0.85	[15]
Terminal temperature difference of evaporator, TTD_{eva} (°C)	2	[16]
TEG temperature, T_{teg} (°C)	38	-
Pump isentropic efficiency, η_{pu} (%)	0.75	[17]

3.2. Energy Analysis

The study of thermodynamic systems requires a thorough understanding of energy. Energy is always constant and can be stored within a system or transferred between systems. Heat (\dot{Q}), work (\dot{W}), and mass flow (\dot{m}), are all forms of energy that can enter or leave a system, following the conservation of energy. Flows into and out of a control volume can be expressed as the following energy balance equation [18].

$$\sum(\dot{Q}_i - \dot{Q}_o) + \dot{W} = \sum((\dot{m}h)_i - (\dot{m}h)_o) \quad (1)$$

Since this system is powered by Parabolic Trough Solar Collectors (PTSC), the numerical modelling of this unit is discussed in greater detail. The PTSC has been modelled using energy balance in the

heat collector element (HCE) according to Ref. [9]. Figure 2 shows the one-dimensional steady-state energy balance for a cross section of the HCE.

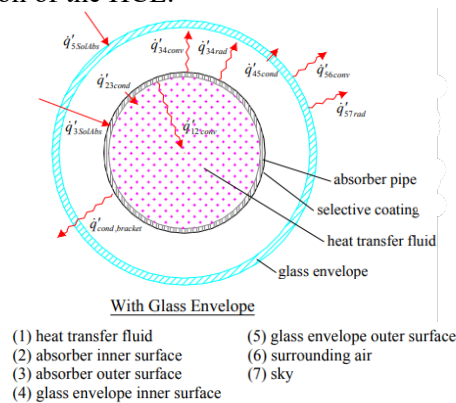


Figure 2. A cross-sectional energy balance of the heat collector element (HCE) in one dimension [9].

As can be seen in Figure 2, the heat transfer fluxes pass through the HCE in the cross section. Detailed energy analysis of the solar collector is reported in Ref. [9].

3.3. Exergy analysis

According to exergy analysis, even though energy is not destroyed, its quality always decreases during various processes. By determining the reason for, location, and size of irreversibility that occur during multiple processes, exergy analysis overcomes some of the weaknesses of energy analysis in systems analysis and enables the designer to reduce them and improve system performance. For each component of an energy system, including entrance energy (F), product energy (P), and destruction energy (D), the exergy balance is as follows [19,20]:

$$\dot{E}_{F,k} = \dot{E}_{D,k} + \dot{E}_{P,k} \tag{2}$$

4. Results

4.1. Daily distribution of solar insolation

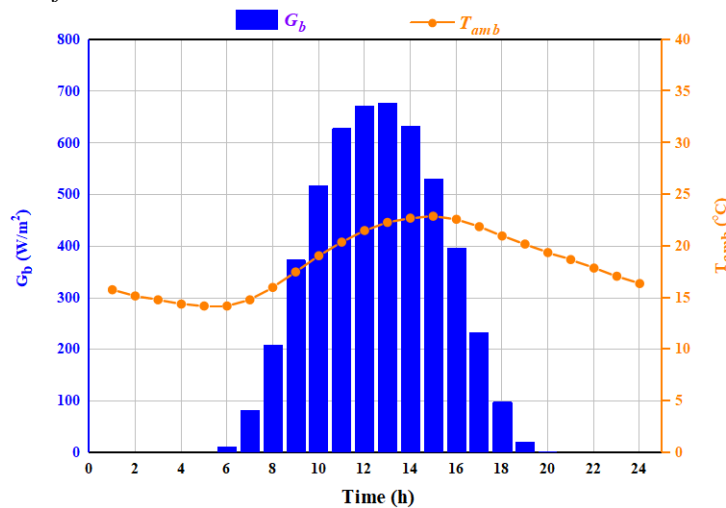


Figure 3. Solar radiation and ambient temperature in Tehran for the average day of the entire year.

Fig. 3 shows the measured total solar radiation and the ambient temperature on Tehran in an average day representing the whole year. According to this figure, solar radiation started at 10.8 W/m² at 06:00 and reached the maximum level of 676.7 W/m² at 13:00, then decreased to 18.9 W/m² at 19:00. These solar radiation data were recorded under environmental conditions.

4.2. Thermal performance and efficiency of the collector

In Figure 4, Q_U is the useful heat output, Q_{load} is the heat loaded, $Q_{lost,ST}$ is the heat loss of the storage tank, T_{ST} is the storage tank temperature and η_{PTC} is the collector efficiency of the PTC. It should be noted that the collector efficiency is Q_U divided by the total input solar energy, which can be found

according to the solar radiation. The performances of the collector through solar and the storage tank are shown in Fig. 4. One can see from Fig. 4 that the collector efficiency obviously increases at the beginning and then, changes a little, remains about 70% for 7 hours. After 18:00, the collector efficiency decreases until the collector cannot collect solar energy.

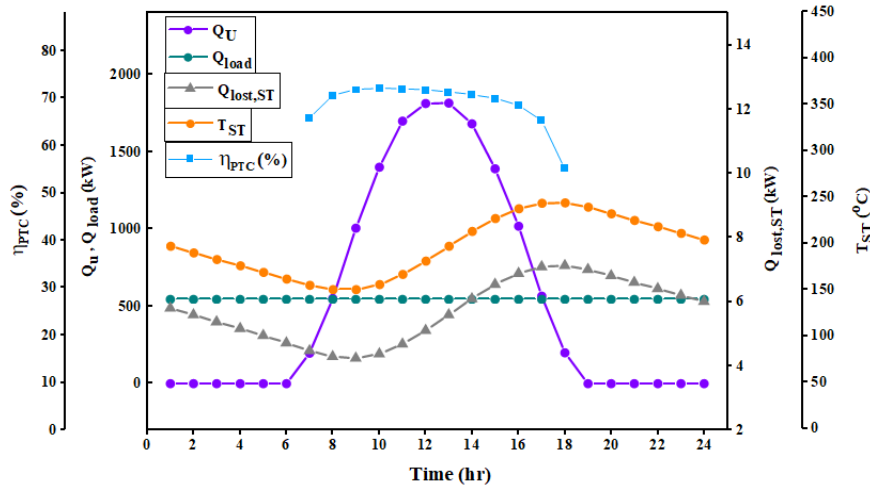


Figure 4. Variation of the Thermal Efficiency and the water temperature inside the storage tank

The maximum energy storage rate is 1816 kW between 12:00 and 14:00, and then the energy storage rate gradually decreases, which is due to the decrease in the heat source. When solar radiation is insufficient (before 8:00 am), the temperature of the storage tank decreases until it reaches 150 ° C. After that, the temperature of the storage tank continues to rise with the intensity of increase in the solar radiation, until reaching the value of 243.5 ° C. After 18:00, the solar radiation intensity is exceptionally low (Fig. 3), the heat collected is less than the heat load, and the temperature of the storage tank drops again. At 1 am, the storage tank temperature is 196.8 ° C.

4.3. Thermodynamic performance

Table 2. Monthly Average Energy and exergy performance of the Proposed System

Units in kW	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	year
Useful solar energy	295.5	389.4	527.2	658.4	760.6	821.9	800.3	733.1	637.9	473.3	334.8	267.7	556.7
Heat loss of storage tank	5.624	5.75	5.884	5.975	5.999	5.933	5.817	5.725	5.68	5.528	5.453	5.495	5.715
Loaded heat	289.9	383.7	521.3	652.4	754.6	816	794.5	727.3	632.2	467.7	329.4	262.3	551
Net output power	3.206	4.269	5.51	6.409	6.421	5.915	5.076	4.857	4.692	3.955	3.152	2.774	4.956
Cooling capacity of EVA 1	8.771	11.61	15.77	19.74	22.83	24.69	24.04	22.01	19.13	14.15	9.965	7.935	16.67
Cooling capacity of EVA 2	22.27	29.47	40.05	50.11	57.97	62.68	61.03	55.87	48.57	35.93	25.3	20.15	42.33
Fuel exergy of the cycle	393	515.7	697.6	869.5	1004	1087	1057	963.9	840.8	623.2	442	354.8	735.7
Product exergy of cycle	20.84	25.68	30.05	32.62	30.49	26.24	21.64	20.42	22.33	20.84	19.27	17.96	26.63
Exergy destruction of cycle	370	487.8	665.2	834.5	971	1058	1033	941.3	816.3	600.3	420.7	334.7	706.9
Lost exergy of the cycle	2.19	2.257	2.32	2.363	2.356	2.296	2.213	2.156	2.141	2.064	2.049	2.1	2.192

The results of the monthly average energy and exergy analysis are depicted in Table 2. As expected, the energy production of each month is strongly dependent on the sunny days of each month. The highest load heat value is obtained in June with 816 kW and the second highest in July with 794.5 kW. The lowest cooling and power production rates are achieved during the winter months, when solar irradiation is not sufficient. More specifically, the lowest loaded heat is observed in December with a value of 262.3 kW.

5. Conclusion

The present study proposed and modeled a solar system with a storage tank to provide cooling throughout the year. Cooling demand is needed throughout the year in hot and arid regions for residential buildings. Using energy and exergy analyses, the proposed system was evaluated. According to the results, the lowest production exergy was achieved in December and November (17.96 and 19.27 kW) and the highest in April and May (32.6 and 30.05 kW). July and June were the months when the system

produced the highest cooling capacity of 87.37 and 85.07 kW, respectively. Furthermore, June and July were the months of highest exergy destruction (1058 and 1033 kW). So, the seasonal variations are acceptable since the transient results have changed according to the solar radiation.

Credit-author statement

Towhid Gholizadeh Baris: Validation, software. Hamed Ghiasirad: Conceptualization, Methodology. Karima Megdouli: Writing. Simin Anvari: Original draft. Bartosz Stanek: Editing. Anna Skorek-Osikowska: Supervision. Lukasz Bartela: Supervision.

References

- [1] Bezaatpour J, Ghiasirad H, Bezaatpour M and Ghaebi H 2022 Towards optimal design of photovoltaic/thermal facades: Module-based assessment of thermo-electrical performance, exergy efficiency and wind loads *Appl Energy* **325**
- [2] Pollerberg C, Ali A H H and Dötsch C 2008 Experimental study on the performance of a solar driven steam jet ejector chiller *Energy Convers Manag* **49** 3318–25
- [3] Vidal H and Colle S 2010 Simulation and economic optimization of a solar assisted combined ejector–vapor compression cycle for cooling applications *Appl Therm Eng* **30** 478–86
- [4] Bellos E, Theodosiou I-C, Vellios L and Tzivanidis C 2018 Investigation of a novel solar-driven refrigeration system with ejector *Thermal Science and Engineering Progress* **8** 284–95
- [5] Salimpour M R, Ahmadzadeh A and Al-Sammarraie A T 2019 Comparative investigation on the exergoeconomic analysis of solar-driven ejector refrigeration systems *International Journal of Refrigeration* **99** 80–93
- [6] Beyrami J and Hakkaki-Fard A 2022 Performance evaluation of the solar-driven multi-ejector refrigeration cycle without an auxiliary heat source *Appl Therm Eng* **217** 119214
- [7] Xu Y, Huang S, Wang J, Song M, Yu J and Shen X 2022 Energy and advanced exergy analyses of novel ejector-compressor partially coupled refrigeration cycle for buildings with less solar energy *Journal of Renewable and Sustainable Energy* **14**
- [8] Anon EES: Engineering Equation Solver | F-Chart Software : Engineering Software
- [9] Forristall R 2003 Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver
- [10] Sukhatme S P 1997 Solar energy : principles of thermal collection and storage
- [11] Ghiasirad H, Rostamzadeh H and Nasri S 2020 Design and Evaluation of a New Solar Tower-Based Multi-generation System: Part I, Thermal Modeling *Integration of Clean and Sustainable Energy Resources and Storage in Multi-Generation Systems* (Cham: Springer International Publishing) pp 83–102
- [12] Shokri Kalan A, Heidarabadi S, Khaleghi M, Ghiasirad H and Skorek-Osikowska A 2023 Biomass-to-energy integrated trigeneration system using supercritical CO₂ and modified Kalina cycles: Energy and exergy analysis *Energy* **270** 126845
- [13] Sokolov M and Hershgal D 1993 Optimal coupling and feasibility of a solar-powered year-round ejector air conditioner *Solar Energy* **50** 507–16
- [14] Sadeghi M, Mahmoudi S M S and Khoshbakhti Saray R 2015 Exergoeconomic analysis and multi-objective optimization of an ejector refrigeration cycle powered by an internal combustion (HCCI) engine *Energy Convers Manag* **96** 403–17
- [15] Habibollahzade A, Gholamian E, Ahmadi P and Behzadi A 2018 Multi-criteria optimization of an integrated energy system with thermoelectric generator, parabolic trough solar collector and electrolysis for hydrogen production *Int J Hydrogen Energy* **43** 14140–57
- [16] Gholizadeh T, Vajdi M and Rostamzadeh H 2019 A new biogas-fueled bi-evaporator electricity/cooling cogeneration system: Exergoeconomic optimization *Energy Convers Manag* **196** 1193–207
- [17] Javanfam F, Ghiasirad H and Khoshbakhti Saray R 2022 Efficiency Improvement and Cost Analysis of a New Combined Absorption Cooling and Power System *Synergy Development in Renewables Assisted Multi-carrier Systems* ed M Amidpour, M Ebadollahi, F Jabari, M-R Kolahi and H Ghaebi (Cham: Springer International Publishing) pp 23–50
- [18] Farzaneh-Gord M, Pahlevan-Zadeh M S, Ebrahimi-Moghadam A and Rastgar S 2018 Measurement of methane emission into environment during natural gas purging process *Environmental Pollution* **242** 2014–26
- [19] Ghiasirad H, Baris T G, Javanfam F, Rostamzadeh Kalkhoran H and Skorek-Osikowska A 2023 Indirect integration of a thermal–mechanical heat pump with a humidification-dehumidification desalination unit *Appl Therm Eng* **230** 120852
- [20] Rostami S, Ghiasirad H, Rostamzadeh H, Kalan A S and Maleki A 2023 A wind turbine driven hybrid HDH-MED-MVC desalination system towards minimal liquid discharge *S Afr J Chem Eng* **44** 356–69