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Thermodynamic Modeling and Multi-Objective Optimization of an Operating Double-Effect Absorption Chiller Driven by Photovoltaic Panel: A Case Study

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Abstract

The double-effect absorption chiller plays a crucial role in achieving temperature and humidity control, surpassing single-effect chillers in terms of capacity and offering ease of operation when compared to double and triple-effect absorption chillers with more complex cycles. The primary drawbacks of the double-effect absorption chiller are its dependence on fuel for both the absorption cycle and the production of the concentrated Lithium Bromide (LiBr) solution. In this study, the use of photovoltaic panels to eliminate fuel consumption through a comprehensive thermodynamic model, involving the adjustment of parameters such as chilled water mass flow rate ($\dot{m}_a$) and solar cycle mass flow rate ($\dot{m}_b$), is investigated to determine the optimal cycle state. The results indicate that the Coefficient of Performance (COP) of the cycle increase as the mass flow rate of chilled water ($\dot{m}_a$) increases and reaches 1.7 in the mass flow rate of 5 kg s^{-1}. Additionally, based on the algorothym in regions with access to the electric grid, it is not cost-effective to use energy generated by photovoltaic solar panels to power the absorption chiller cycle.

Keywords: Double-effect absorption chiller, Lithium bromide solution, Multi-objective optimization, Photovoltaic panel, Thermodynamic modeling, Thermodynamic modeling.

1 | Introduction

Due to rapid population expansion and excessive consumption of fossil fuels, nations are confronted with indisputable challenges [1]. This leads to the release of GreenHouse Gases (GHG), which results in climate change, global warming, the melting of ice and glaciers, the occurrence of acid rain, and ozone depletion.

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Existing energy infrastructures are not environmentally sustainable and need to be updated in the coming years [2]. Integrated systems offer various benefits, including the production of power, cooling, and heating. The optimization of heating and cooling systems is pivotal within the building energy sector. Increasing the effectiveness of these systems and diminishing their carbon dioxide (CO2) emissions are becoming key priorities [3]. The mentioned challenges can be divided into two main categories: energy shortages for increasing electricity production and climate changes leading to global warming. The proposed solution to address these problems involves prioritizing the use of renewable energy as the primary energy sources. It is evident that renewable energy sources are not only more sustainable than fossil fuels but are also recognized for their environmental cleanliness and higher efficiency.

The use of solar energy can decrease the amount of carbon dioxide that is usually produced in the world [4, 5]. Therefore, solar energy can be a good selection to diminish the electricity consumption in air conditioning [6]. In addition to this, solar energy is obtained for free from the surrounding natural environment.

Air conditioning is accounting for consumption of roughly 40% of building energy and uses a lot of electricity and chillers play a considerable rule in air conditioning [3]. The two coomon type of absorption chillers are the single effect and the double effect. The single-effect kind of absorption chillers has been popular since the 1960s, while the double-effect variety wasn't invented until the 1980 [4].

Single-effect and double-effect absorption chillers are two distinct types of thermally driven cooling systems utilized across industrial and commercial sectors. The fundamental principle underlying single-effect absorption chillers is absorption refrigeration, where a designated working fluid, often Lithium Bromide (LiBr) solution, absorbs moisture vapor to generate cooling. To reset the LiBr solution, these chillers depend on an external heat source, typically derived from natural gas or steam, making them relatively energy-intensive and less efficient in comparison to alternative cooling technologies.

Conversely, double-effect absorption chillers represent an evolutionary stride in absorption cooling technology. They operate on a dual-stage concept, signifying the "double-effect." In the first stage, a high-temperature heat source initiates vaporization of the LiBr solution. This vapor, in turn, becomes instrumental in the second stage, where it further absorbs moisture vapor, resulting in a more pronounced cooling effect. This two-stage process, when integrated, equips double-effect absorption chillers with the capacity to deliver augmented cooling while still mandating a heat source for the regeneration process. This heightened efficiency renders them a more appealing choice for scenarios prioritizing energy conservation and sustainability, notwithstanding their greater complexity and installation and maintenance costs [7]. The double-effect chiller, although needing a slightly higher operating temperature, such as from concentrated solar or geothermal energy, offers superior economic and environmental performance compared to the single-effect chiller. Consequently, this study opts for the utilization of a double-effect chiller assisted with solar photovoltaic [8].

Recent research on double-effect chillers, as outlined in the literature, encompasses a wide array of modeling studies with the aim of refining their operational strategies. These studies also involve the analysis of both thermodynamic and economic performance, including optimization techniques, and their integration with various energy systems such as district energy systems. Avanessian et al. [9] delved into the examination of series and parallel chiller configurations, revealing a significant correlation between inlet temperature, mass flow rate, and energy performance. Mussati et al. [10] optimized the design of double-effect chillers using a single objective function that took into account exergy, heat-transfer area, and cost. Moreover, extensive multi-objective optimization endeavors have been carried out, which consider energy, exergy, and economic factors.

Meanwhile, in the case of researchers who have investigated the the exergy analysis of single-effect and double-effect absorption chiller systems using LiBr/H_2O, [11–18]. Most of these research examined how generator, absorber, condenser, and evaporator temperatures, solution circulation ratio, and heat recovery ratio affect cycle performance. Moreover, the number of effects in the absorption chillers is important parameters that should be selected properly to maximize the system operation. Lubis et al. [19] investigated a single-double-effect absorption chiller system. They maximised performance of a reference single-double-effect absorption chiller by adjusting some parameters. According to the findings of their analysis, the actual Coefficient of Performance (COP) of their system has the potential to rise by between 3 and 5%. As an added bonus, they demonstrated that a notable reduction in primary energy usage is possible.

Solar-assisted heating and cooling absorption systems were investigated by Shirazi et al. [20] using four different configurations. Energy, cost, and environmental (3E) evaluations were carried out on the from experimental work. Their results demonstrated that although the high primary energy saving can be achieved; the economic performance of these configurations is not suitable. However, if there are no concern about financial sources, the configuration has been suggested that is economically feasible and achieving a payback period of 4.1 years.

Double effect chillers can be classified with the working fluid (internal fluid) that flows through the regenerators and disrobers. Safarnezhad et al. [21] conducted exergy-based study on the parallel flow double-effect absorption chiller. In this study, exergy destruction of each component is obtained and imposed in the exergy analysis. The thermodynamic modeling of cycle is expressed and exergy efficiency is determined for components. Thermodynamic optimization imposed for obtain the maximum COP. The results show the exergy destruction of the endogenous section is much larger than the exogenous section it is illustrates that concentrate on the component efficiencies to improve system performance is suitable manner. Behzadi et al. [22] proposed a system includes PVT, a double effect absorption chiller and a geothermal unit. This study conducted Energy, Exergy And Exergoeconomic (3E) analyses on this cycle and for this result impose the multi-objective optimization. The results show overall exergy efficiency which is 10.59% in addition to the 11.4 kW cooling load is extracted from PV. Moreover, geothermal unit increase COP of cycle about 15%. These researcher, used form Genetic Algorothym implement to optimization technic by the use of MATLAB and earned the optimal value of exergy efficiency and total product unit cost that respectively (13.07%, 36.97$ GJ^{-1}). Zheng et al. [23] study about steam operated double-effect absorption chiller heat pump. In this study, system simulated and, mathematical model developed and validated by the experiments, and maximum deflection is about 13% and 19% in heating and cooling, respectively.

Optimization presented with mathematical models and, result of this optimization shows optimum combination of heat transfer temperature difference. Two new configurations of a double-effect absorption chiller are one with series flows and one with parallel flows, were proposed by Chahartaghi et al. [24]. Critical parameters such as mass, concentration, and energy balance equations were examined in these configurations. The best possible COP for the system has been calculated after careful consideration of these factors and the application of a Genetic Algorithm to optimize the system for both series and parallel flow.

Although this study has explored the use of photovoltaic panels to reduce fuel consumption in double-effect absorption chillers, there exists a notable research void concerning the mechanisms behind the observed decline in the COP as the chilled water mass flow rate ($\dot{m}_a$) increases. Additional investigation is warranted to gain a deeper understanding of the factors responsible for this COP decrease and to develop strategies or modifications that can optimize the cycle's efficiency across different load conditions.

Furthermore, the research has emphasized the limited cost-effectiveness of employing photovoltaic-generated electricity to power absorption chillers in regions with access to the electric grid. This discovery raises questions about the economic viability of integrating photovoltaic panels into double-effect absorption chiller systems. Further research is essential to assess the economic feasibility of this technology in various geographical areas and under diverse operational circumstances, taking into account factors such as electricity pricing, solar radiation levels, and system expenditures.

Addressing these research gaps will contribute to the advancement of more efficient and economically sustainable photovoltaic-integrated double-effect absorption chiller systems. Such advancements have the potential to revolutionize temperature and humidity control in various applications while simultaneously reducing the environmental impact associated with traditional fuel-dependent absorption chillers.

This research looks into the viability of using a photovoltaic solar panel to power a double-effect absorption chiller. The feasibility of using a photovoltaic solar panel to generate hot water for powering a double-effect absorption chiller is studied. A parametric analysis and a multi-objective optimization are carried out with the help of the simulation that has been provided.

2 | System Description

Absorption chillers use the absorber and generator for chilling process and LiBr is a most common absorber that used in such systems. In comparison to the type of absorption chiller that only has one effect, the type that has two effects has an excellent COP. Actually, operation of double-effect type of chillers similar to the single one but in double-effect the density of LiBr-water solution increase with the use of high and low temperature generator. This increasing cause to enhancement the COP of such systems. While low electricity consumption is the advantage of absorption chillers, using the fossil fuel is most important challenge that can solve with renewable sources like solar energy.

The double-effect absorption chiller that relied on solar power instead of fossil fuel was the primary research topic for this paper. In this study, the double-effect absorption chiller has a photovoltaic panel, evaporator, condenser, High-Temperature Solution Heat Exchanger (HSX), Low-temperature Solution heat Exchanger (LSX), and pumps to circulate LiBr-water solution.

With considering that the main problem of double effect absorption chillers is using from fossil fuel in High-Temperature Generator (HTG) many works imposed a way to eliminate fossil fuels; solar assisted panels is the most used for this problem. In a large part of carried out studies solar thermal collector was used to solving the problem of generator but in this study the photovoltaic panel is employed.

In double-effect absorption, water chills with spraying refrigerator on the evaporator pipes. This spraying accurse in a vacuum conditions (low pressure). Low pressure the only reason to chilling the water and this condition cause to produce saturated vapor in this space. This vapor cause to increase the pressure of space and cooling process is disrupted. In order to solve this problem LiBr is used as absorber. Absorber takes the destructive vapor out of space and LiBr solution diluted after absorption. Diluted LiBr loses its ability to absorb vapor and most components of the absorption chiller used to inspissation of diluted LiBr. Diluted LiBr guides to LSX and HSX and after these parts LiBr solution enters HTG. In this section, the energy that gives from solar panel impose to the LiBr solution and massive part of the water that absorbed convert to vapor. After that LiBr solution divide to section, concentrated LiBr and water vapor. In double-effect absorption chillers the vapor that produced in HTG use as hot source in Low-Temperature Generator (LTG) and the concentrated lithium uses this hot source to become thicker. Main difference between single and double effect absorption chillers is in this issue and it cause to increase the absorb capacity of LiBr. LiBr solution after these levels goes to absorber gage and this cycle repeat. It should be noted that solar cycle utilizes roughly 12% of the panel's useful power for drive the generator. The novelty of this work is using from photovoltaic panel as solar source to provide energy of HTG.

3 | Methodology

In fact this study by the use of photovoltaic panel, investigates the optimum COP of plan with manipulating the characteristics like mass flow rate of chilled water ($\dot{m}_a$) and mass flow rate solar cycle ($\dot{m}_b$) and temperature difference of chilled water in a double effect absorption chiller with LiBr as the coolant. At first the energy and mass balance have been written and based om thermodynamic rules, the COP and economical aspects of the cycle have been investigated.

The abbreviations in *Fig. 1* are as follows: HTG stands for High-Temperature Generator, LTG for Low-Temperature Generator, LSX for Low-Temperature Solution Heat Exchanger, HSX for High-Temperature Solution Heat Exchanger, and ABS for Absorber.

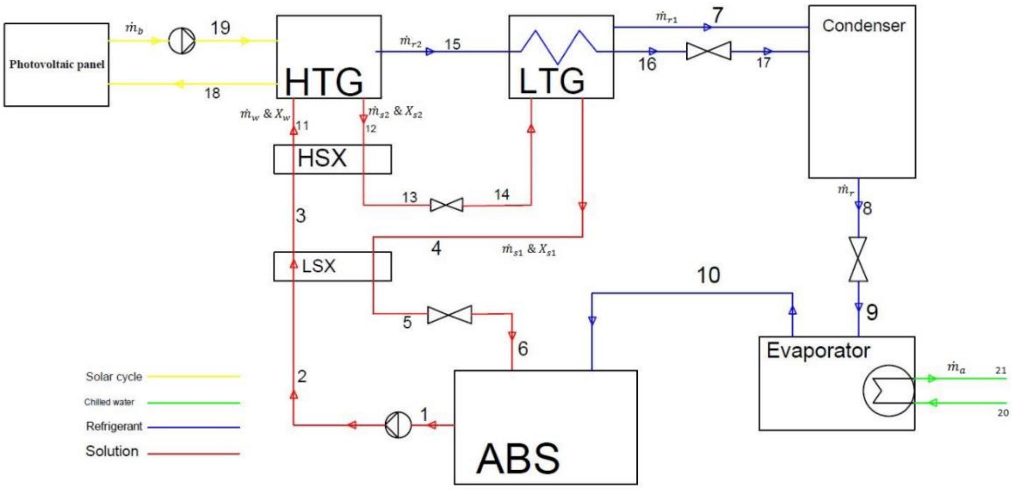


Fig. 1. Schematic of a solar assisted double-effect LiBr/H2O absorption chiller.

4 | Modeling

4.1 | Thermodynamic

The analysis of the absorption system's energy and exergy makes use of the conservation of mass and of species, as well as the first and second laws of thermodynamics. These equations specify below:

Mass conservation

$$\sum \dot{m}_i = \sum \dot{m}_e \, . \tag{1}$$

Species conservation

$$\sum \dot{m}_i X_i = \sum \dot{m}_e X_e \, . \tag{2}$$

First law of thermodynamics

$$(\sum \dot{m}_i h_i - \sum \dot{m}_e h_e) + (\sum Q_i - \sum Q_e) + w = 0. \tag{3}$$

Second law of thermodynamics

In steady state and regardless of potential and kinetic energy changes exergy equilibrium equation for one system written:

$$\dot{E}_D = \underbrace{[\Sigma\left(1-\frac{T_o}{T}\right)\dot{Q}]_{in} + [\Sigma\left(1-\frac{T_o}{T}\right)\dot{Q}]_{out}}_{1} + \underbrace{(\Sigma\ \dot{m}_i e)_{in} - (\Sigma\ \dot{m}_i e)_{out}}_{2} + \dot{W} = 0\, . \tag{4}$$

Where, $\dot{E}_D$ is the exergy destruction of process that happens under consideration components. The term 1 of *Eq. (4)* are the exergy associated with heat transfer $\dot{Q}$ and part 2 of this equation demonstrate total input and output exergy flow.

Thermal exergy loss rate ($\dot{E}_L$) is related to external irreversibility, which occurring because of temperature difference between the control volume and the surroundings. In this case, the thermal exergy loss rate given by:

$$\dot{E}_{L_i} = \Sigma\left(1-\frac{T_o}{T_i}\right)\dot{Q}_i. \tag{5}$$

Where $\dot{Q}_i$ is the heat rejected by the component under consideration and T_i, the temperature at its boundary. We can rewritten the *Eq. (4)*:

$$\dot{E}_{D_i} + \dot{E}_{L_i} = [\sum\left(1-\frac{T_o}{T}\right)\dot{Q}]_{in} + (\sum\ \dot{m}_i e)_{in} - (\sum\ \dot{m}_i e)_{out} + W. \quad (6)$$

Mass, material and energy balance of the system

Eqs. (7)-(11) describe the mass and material balance at the HTG, the LTG, and the condenser.

High-temperature generator:

$$\dot{m}_w = \dot{m}_{s2} + \dot{m}_{r2}. \quad (7)$$

Where $\dot{m}_w$ and $\dot{m}_s$ respectively is the mass flow rate of weak solution and strong solution.

$$\dot{m}_w X_w = \dot{m}_{s2} X_{s2}. \quad (8)$$

Low-temperature generator:

$$\dot{m}_{s2} = \dot{m}_{r1} + \dot{m}_{s1}. \quad (9)$$

$$\dot{m}_{s2} X_{s2} = \dot{m}_{s1} X_{s1}. \quad (10)$$

Condenser:

$$\dot{m}_r = \dot{m}_{r1} + \dot{m}_{r2}. \quad (11)$$

The energy balance in each component of a solar assisted double-effect system is given by the following equations:

$$\dot{Q}_{HTG} = \underbrace{\dot{m}_{r2}h_{15} + \dot{m}_{s2}h_{12} - \dot{m}_w h_{11}}_{1} = \underbrace{\dot{m}_1(h_{18} - h_{19})}_{2}. \quad (12)$$

In this equation, Section 1 illustrates the solution part, energy balance and Section 2, shows the balance of hot water that comes from solar cycle part and heat of it, transfers to the weak solution.

$$\dot{Q}_{ABS} = \dot{m}_r h_{10} + \dot{m}_{s1} h_6 - \dot{m}_w h_1. \quad (13)$$

$$\dot{Q}_C = \dot{m}_{r1} h_7 + \dot{m}_{r2} h_{17} - \dot{m}_r h_8. \quad (14)$$

$$\dot{Q}_E = \underbrace{\dot{m}_r(h_{10} - h_9)}_{1} = \underbrace{\dot{m}_3(h_{20} - h_{21})}_{2}. \quad (15)$$

Where, *Eq. (15)* in Section 1 illustrates the cooling water energy balance and in Section 2 shows the chilled water energy balance.

$$\dot{W}_p = \dot{m}_w(h_1 - h_2). \quad (16)$$

COP of the system

$$\text{Energy input} = \dot{Q}_{HTG} + \dot{Q}_E + \dot{W}_p, \quad (17)$$

$$\text{Energy output} = \dot{Q}_C + \dot{Q}_{ABS}, \quad (18)$$

$$\text{Coefficient of Performance(COP)} = \frac{\dot{Q}_E}{\dot{W}_p + \dot{Q}_{HTG}}. \quad (19)$$

4.2 | Economic Analysis

The financial implications of the proposed system are examined here. One of the most crucial steps in developing any engineering design is conducting an economic analysis. In this section, by the use of engineering economic methods the cost analysis of solar assisted double-effect absorption chiller is presented.

4.2.1 | Engineering costs

Engineering project expenses may range substantially depending on a number of factors. All outputs have the same fixed costs, while output has a direct effect on the variable costs. Marginal cost refers to the additional variable expense incurred when producing a single additional unit. While the average cost is the total cost divided by the number of units [25].

$$\text{Total cost } = \text{Total fixed cost } + \text{ Total variable cost.} \quad (20)$$

In the present work, we compute the fixed cost includes double-effect absorption chiller and photovoltaic panels and the variable costs can be discounted due to their low cost. Total variable and fixed costs is computed for the different discharges of solar cycle and chilled water and impose in to the result section [25].

4.2.2 | Present value

The present value is a function of time t and interest rate *i* [26].

$$\text{PV} = \text{f(t. i)}. \quad (21)$$

In order to evaluate the PV should be calculate the Future Value (FV) (cost and benefit), that given by:

$$\text{PV} = \text{FV} * (1 + \text{i})^{-\text{n}}. \quad (22)$$

Where n is period of time that system used in this paper and i is the interest rate. Net Present Worth (NPW) is the net difference of the present costs and benefits is the NPW [22].

$$\text{NPW} = \text{PV(Benefits)} - \text{PV(costs)}. \quad (23)$$

The lifetime worth of a system is determined by adding up all of its costs and benefits over its entire lifespan. So that it may include a full accounting of the system's costs and benefits in the present study's findings.

By the use of production result of the Abbaspour School of engineering photovoltaic panels the thermodynamic analysis, is preformed.

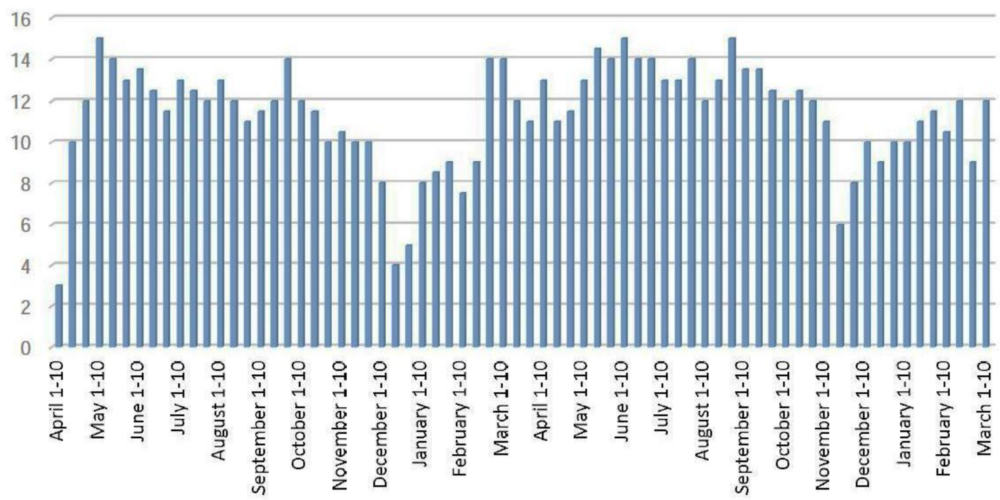


Fig. 2. Energy production of the panels since April 2016 to March 2018.

However, the results of the solar panel (shown in the *Fig. 3*) used to provide the energy that needs to drive the absorption cycle. The energy that demands from absorption cycle computed by the equations that introduced in Section 3 and with this data we can choose the best type of solar panel, and calculating the number of solar panel to drive the solar cycle. In economic part, the solar panel and whole absorption cycle price computed and imposed in the result section. These prices calculated with considering the engineering methods and annually inflation that can effect on the present work.

Fig. 3. Photovoltaic panels of the Abbaspour School of Engineering.

5 | Results and Discussion

5.1 | Parametric Analysis

Parametric study in order to investigation of effect of main decision variables on the cost and the COP of the system. First investigation is about the manipulation in the chilled water mass flow ($\dot{m}_a$). In *Fig. 4* variation of the COP and cost with changing in the $\dot{m}_a$ can be seen. This figure illustrate that COP is constant with changing in $\dot{m}_a$ but cost increasing significantly.

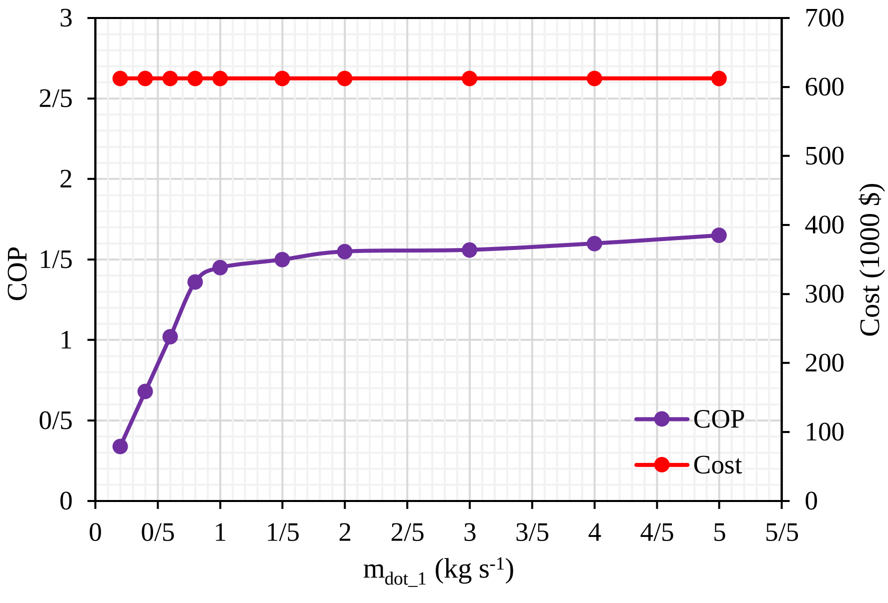


Fig. 4. variation COP and cost with changing $\dot{m}_a$.

Fig. 5 depicts how the cost and COP change in response to alterations in the mass flow of the solar cycle ($\dot{m}_b$). According to the *Fig. 5*, cost increase very significantly and COP of the system decreasing with, raising the $\dot{m}_b$.

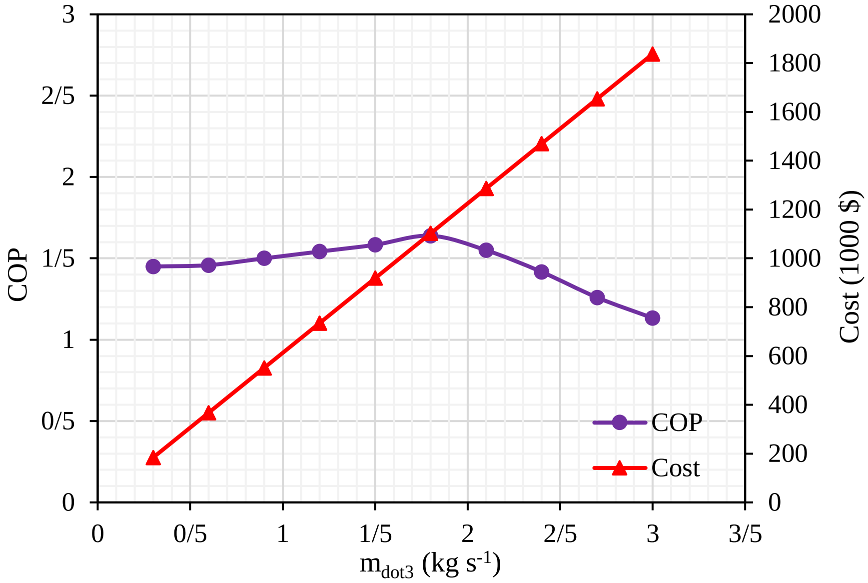


Fig. 5. Variation COP and cost with changing $\dot{m}_b$.

Parametric studies were run to determine the optimal supply and demand temperatures for chilled water, and the findings are depicted in *Fig. 6*. It's a suitable comparison between the cost and COP that illustrate low economic efficacy for the state that difference temperature increasing.

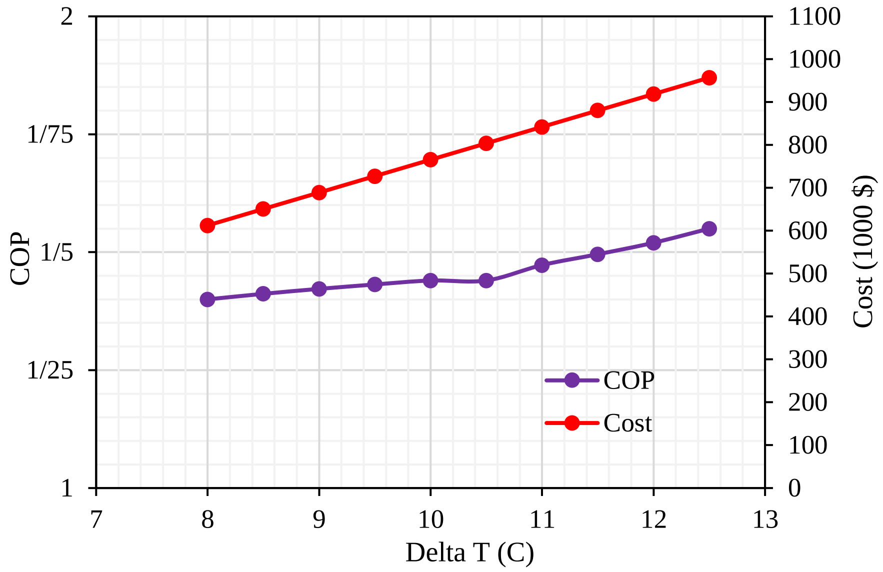


Fig. 6. Variation COP and cost with changing difference temperature of the inlet and outlet chilled water.

5.2 | Optimization

The outcomes of the optimization performed on the system under study are reported in this section. The optimal configurations of the investigated system are identified by optimising it with respect to two objective functions: the performance coefficient and the overall cost. The COP and the total cost of the system are both optimised using a genetic algorithm-based multi-objective approach.

The Pareto front diagram depicted in *Fig. 7* shows the optimal operating states for the PV-assisted double-effects absorption chiller system. The findings demonstrate that a substantial range of variation exists between two established goal functions as a result of choosing between distinct states on the Pareto diagram. The results show that the system's price can shift anywhere from $940125 to $2112031 and that the COP can shift between 0.235 and 2.324. On the Pareto diagram, there are four separate points that are shown in order to facilitate a better understanding of the behaviour of multiple optimum conditions. It is clear that moving from point D to point C will result in a significant rise in overall cost, whereas the COP value will only move within a limited range.

In addition, for the purposes of this particular scenario, points A and C correspond to the single-objective optimization with the total cost and COP as the objective functions, respectively.

The decision maker criteria play a significant role in selecting the optimal optimum state of the optimization problem. The concept of ideal point is an appropriate method for selecting a point as the system's optimal state, as it can help choose which point to choose. A hypothetical place on the Pareto front where the values of both objectives are maximised can be used to introduce the concept of the ideal point. A Pareto front diagram, also known as a Pareto front or Pareto frontier, is a graphical representation used in multi-objective optimization and decision-making to visually convey trade-offs between multiple conflicting objectives or criteria. It is named after the Italian economist Vilfredo Pareto, who introduced the concept of Pareto efficiency. Despite the obvious impossibility of the ideal point on the Pareto diagram, it might be useful for narrowing down a list of potential optimal conditions to a single one. Taking the best approach For the examined system, the optimal state B may be the one that minimises the difference between the current and ideal states. Both the COP and the total cost of the system come in at 2.036 for point B, with the total cost coming in at $1649804.4.

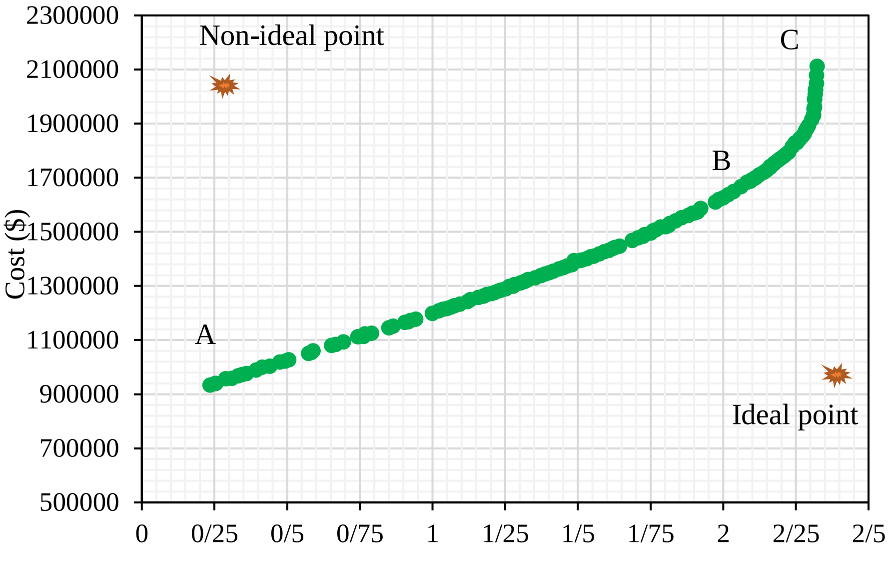


Fig. 7. Pareto front diagram for studied PV assisted double effects absorption chiller based on COP and total cost objective functions.

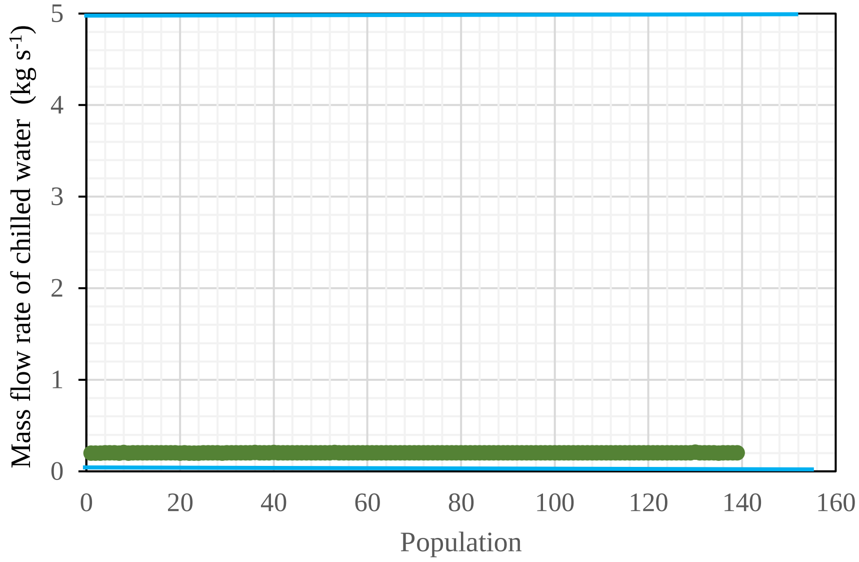
In addition to better understanding the characteristics of Pareto front diagram, the specification of different points is given in *Table 1*.

Table 1. Specification of different points on the Pareto diagram include decision variables and objective functions.

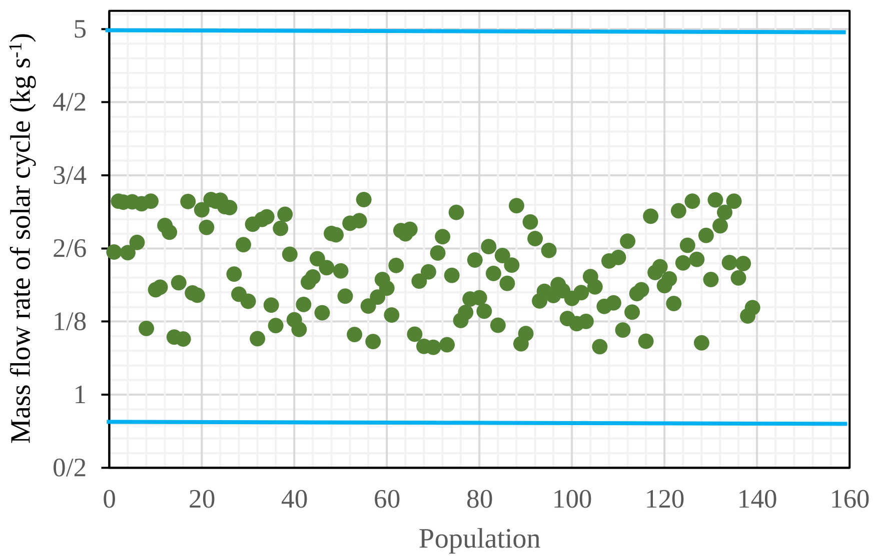
Point	COP (-)	Total cost ($)	$\dot{m}_a$ (kg s^{-1})	$\dot{m}_b$ (kg s^{-1})	ΔT ℃
A	0.23	933785	0.204	1.52	8.03
B	2.04	1649804	0.201	2.68	8.04
C	2.32	2112031	0.200	3.10	8.88
D	2.29	1892943	0.202	3.07	8.05

To better understanding the behavior of optimum state obtained using MOO GA based in Pareto front form, the scatter distribution of decision variables in various optimum states are illustrated in *Fig. 8.a-8.c* Generally more scattered distribution means that there is strong conflict between objective functions. As it can be seen in *Fig. 8.a*, the value of $\dot{m}_a$ as the one of decision variables tend to be at the lower possible value in the range for this parameter. This trends mean that there is a weak conflict between defined objective functions with variation of $\dot{m}_a$. In addition, *Fig. 8.b* represents the distribution of $\dot{m}_b$ in the range between 0.3 and 5 kg s^{-1}. The result indicates that the optimum value of this parameter can be change between 1.6 kg s^{-1} and 3.2 kg s^{-1}. Selecting a unique value among the suggested by the MOO depends on the decision maker criteria.

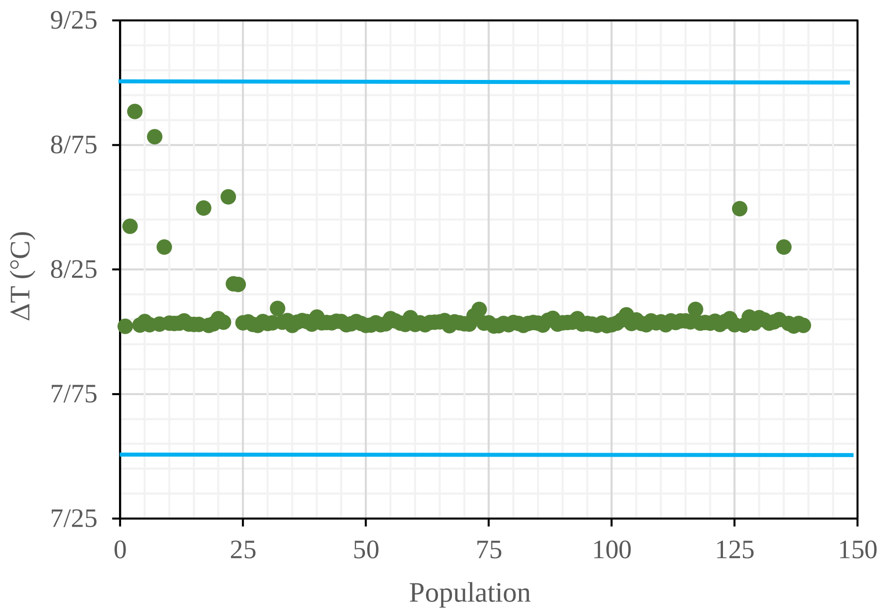
Fig. 8.c represent the scatter distribution of temperature difference of chilled water in the optimum states proposed by Pareto front. As it can be seen the values of temperature difference of chilled water is dispersed around 8 kg s^{-1} which indicated that there is not a strong conflict between objective function with changing this decision variable.



a.



b.



c.

Fig. 8. Scatter distribution of decision variables in their allowable range; a. mass flow rate of solar cycle, b. mass flow rate chilled water, c. temperature difference of chilled water.

6 | Conclusion

Present study explores the use of photovoltaic panel to eliminate fuel consumption in the system through a complete thermodynamic and economic modeling appropriate criteria is defined and the change of parameters like chilled water discharge mass flow rate ($\dot{m}_a$) and solar panel discharge mass flow rate ($\dot{m}_b$) to find optimum state of cycle is investigated. The major conclusion of the present study can be expressed as follow:

I. With increasing the chilled water mass flow, from 0.5 kg s-1 to 1 kg s-1 COP of cycle increase significantly and reached 1.5, while the cost of the instruments that used in cycle is constant. However, after 1 kg s-1 approximately increasing in mass flow cannot make any change in COP and cost.

II. With increasing the solar panel mass flow rate, from 0 kg s-1 to 3.5 kg s-1, COP was increased upto the mass flow rate of 1.8 kg s-1 and then witnessed a decline. Meanwhile the cost was decreasing in all mass flow rates.

III. The study's results demonstrate that the optimal state achieved through the application of Multi-objective optimization based on a genetic algorithm is dependent on the decision-maker criteria. State B is the best possible configuration of the investigated system since it minimises the deviation from the ideal point.

IV. This study in economic part that absorption chiller cycle driven by use photovoltaic solar panel, is not economically for areas, where access to the electric network.

Future research can delve deeper into understanding the relationship between the mass flow rate of chilled water ($\dot{m}_a$) and the COP in photovoltaic-integrated double-effect absorption chillers. Investigate strategies and system modifications to counteract the observed decrease in COP as $\dot{m}_a$ increases, aiming to maintain or enhance system efficiency under varying load conditions.

Author Contributions

Saba Arshizadeh contributed to conceptualization, data analysis, and writing – original draft. Shoaib Khanmohammadi supervised the project and handled methodology and review. Ali Jahangiri assisted in investigation and validation of results. Seyed Mahdi Hossein Sajedi helped with data curation and visualization. Hitesh Panchal contributed to the thermodynamic modeling and optimization. Chander Prakash participated in the review and editing process. Naveen Kumar Gupta was responsible for the technical support and supervision.

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Data Availability

The data supporting the findings of this study are available within the paper and can be made available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest related to this work.

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Appendix

Nomenclature

e. Ė	Specific exergy, exergy	($kJ\ Kg^{-1}$), (KJ)
h	Specific enthalpy	($kJ\ Kg^{-1}$)
ṁ	Mass flow	($kg\ s^{-1}$)
Q̇	Heat transfer rate	(**Kw**)
T	Temperature	(°C)
t	Time	(s)
Ẇ	Work transfer rate	(**Kw**)
X	Mass fraction of Lithium bromide in solution	(-)
Subscripts		
0	Ambient	
1, 2, …	Represent state points in Fig. 1.	
ABS	Absorber	
a	Chilled water	
b	Solar cycle	
C	Condenser	
COP	Coefficient of Performance	
D	Destruction	
E	Evaporator	
e	Exit	
FV	Future Value	
GA	Genetic Algorithm	
HSX	High-temperature solution heat exchanger	
HTG	High-Temperature Generator	
i	Inlet, represents the any component of the system under consideration	
in	Input	
L	Loss	
LSX	Low-temperature solution heat exchanger	
LTG	Low-temperature generator	
NPW	Net present worth	
out	Out	
P	Pump	
PV	Present value	
PVT	Photovoltaic/thermal	
r	Refrigerant	
s	Strong solution	
w	Weak solution	
Greek letters		
Σ	Represents sum of	