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Integrated Techno-Economic Evaluation of Solar Energy Conversion Systems: Linking Efficiency with Economic Performance

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ABSTRACT

The paper discusses the potential of solar energy as a renewable form of power in hydronic environments with sunlight. A techno-economic study was conducted on whether solar thermal collectors could sustainably and effectively operate small-scale experimental models of thermal desalinization conceived by the very researchers who developed them. Besides temperature, irradiance and heat flow; thermal efficiency as monitored from the temperature of the panel while it dissipates heat, type of fluid used and angle at which the panel is oriented relative to the sun's path comprises. Results indicated that under adequate sunlight and favorable conditions, solar thermal collectors are highly efficient in converting sun's rays into usable heat. Technoanalysis combination with economic analysis helps to develop bigger models applicable for different locations and enhances understanding about the feasibility of these systems .This research possesses a significant scientific merits which will attract future solutions based on solar energy and water having sun as their primary energy source.

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1. Introduction

Environmental concerns grow as the world perpetually depends on fossil fuels while global energy demand continues to increase added a swift change toward alternative sources of energy in recent decades. As the disparity widen between supply and demands in both water and energy sector specifically in hot arid regions there is apparent emphasize sustainability and efficiency with economic importance thus this necessitated implementation new innovation that integrated both aspect thus create more emphasize for such solution Solar as one of most promising source its practical available everywhere plus its environmentally friendly(no emission) make it perfect to be used together with water desalinization as well electricity production.[1-5]

There is a techno-logical imperative in those countries where seawater desalinization is the primary mode of obtaining water, to smart solar energy. Multi-effect distillation (MED) technologies are among the most popular system types due to their reliability and efficiency. Technologically efficient and environmentally friendly buildings integrate them with a solar thermal energy system output increased while still maintaining an environmental impact that is minimized. [6-10] The paper analyzes different available market collector types together with estimating their potential to deliver constant renewable thermal power demanded by desalinization units' operation since favorable conditions directly influence both production level as well as efficiency of collectors this type of research becomes highly significant within sunny environments. [11-14]. Therefore, this scientific research study will analyze both technically and economically the solar thermal collectors, as these devices have the capacity to deliver energy at different stages to multiple flash desiccation. The method is conceptual, theoretical and practical with on site experiments better to elucidate effectiveness of these systems, factors affecting their performances and realizable potential in terms of water production rate with associated costs. Through this dual mode of analysis the researcher endeavors eventually from a scholarly perspective facilitating future system designs more efficient relative to water and energy requirements in sunny regions.

2. **Research questions**

1. How does the technical efficiency of solar energy conversion systems affect their economic performance in different climatic and geographical contexts?

2 .How can effective integration between technical efficiency and economic feasibility be achieved in solar energy conversion systems to achieve energy sustainability?

3. Research Hypothese

There is a strong positive correlation between the technical efficiency of solar energy conversion systems and their economic viability, such that improving technical performance leads to a reduction in energy production costs and an increase in return on investment, especially when considering climatic conditions and government support.

4. Research Objectives

1. Thermal performance assessment of the collectors, temperature, solar irradiance, and thermal output will be observed during the daily operational period.

2. To analyze the net heat output or thermal efficiency of the system and establish its relationship with different parameters which include losses, properties of fluid and orientation of the system with respect to the sun's path.

3. To check the possibility of using the obtained thermal energy for running MED desalination units and making a theoretical estimate on the water quantity produced.

5.Literature Review:

5.1 Thermo-economic analysis and structure simulation of parabolic solar collector working with desalination setup . 2024

The evaluated both thermal efficiency and cost-effectiveness within a parabolic trough solar collector integrated with a desalination unit. It also reported whether wind speed-whether considering the position of the collector-affects deflection as well as thermal efficiency to improve that latter parameter. As wind speed increases, it found, the system's thermal efficiency declines. The calculations included an end torsion angle at reflector shaft; ANSYS analysis addressed structural behavior under different conditions Results presented that shaft torsion angle rosed at the three roles. Also discovered was that fluid temperature flows within the collect or were non uniform due to solar radiation variations.The use of higher latent heat materials to reduce therma lfluctuations proved positivein thispaper ,a spiral tube Phase Change Material(PCM) installed insidethereceiver pipe . Results show that maximum torsion angle is obtained at a wind speed of 30 km/h at the best position. The greater is the deviation from the focal line, the more heat loss; therefore, it has been optimized to a maximum wind speed of 124 km/h. Water outputs at different wind speeds-15, 22 and 30km/h were noted as 722,557 and351 ml/m2for4hoursrespectively.An economic analysis revealed that suggested system will decrease payback period

5.2 Experimental analysis of multi stage water desalination system using parabolic solar evacuated trough with solar tracker.2017

This study reports the experimental evaluation of a multi-stage solar desalination unit integrated with a parabolic trough solar collector equipped with a focal pipe and a basic serpentine-type heat exchanger. The receiver tube, measuring 2 meters in length and 6 millimeters in diameter, circulates a diluted water–antifreeze mixture as the working fluid in a closed-loop system through both the focal pipe and the serpentine coil. The receiver is enclosed with transparent borosilicate glass to prevent the heat transfer by convection to the surrounding (ie. the greenhouse effect is utilized) and the space between glass and tube is evacuated, Aluminum serpentine of the heat exchanger is installed in bottom of still .It is attached extremely with thermally insulated pipelines through the trough .The fluid forced flow using small pump which powered by PV system. The multi-stage type solar still water desalination system was designed to recover latent heat of evaporation and condensation in 2 stages. Test results prove that the system generates about 3.6 kg of fresh water within only five hours from 10:30 to 15:30 .

5.3 SOLAR DESALINATION SYSTEM USING PARABOLIC COLLECTOR.2013

The research aims at designing a An enhancement module aimed at improving the performance of solar water desalination, utilizing a dark-colored copper heat exchanger is placed at the bottom pool water of the distillation

tank and firmly connected to the trough by thermally insulated piping, small pump injects oil into its flow .The parabolic trough will be made to follow automatically with simple mechanism hence more solar radiation can be collected that will make effective proposed solar desalination system. Saltwater is Warmed using solar energy with support from hot oil running through a heat exchanger inside it .The experiment took place in September , October and November 2012 Egyptian Meteorological Office provided average typical climatic condition data for Cairo on specific dates used as experimental site. The paper carries out a comparative study between the traditional and modified solar desalination stills, meanwhile also presenting an economic analysis of the existing system. There was a mean increase of 41.07% in fresh water yield while overall thermal efficiency(23%)of the modified system under active modification has been attained.

6.Experimental Methodology

6.1Experimental Design

A thermal testing platform was constructed. A variable speed and flow rate pump was regulated using a digital flow meter at the inlet and a differential pressure gauge across the porous section to ensure consistent heat transfer from the wall to the liquid, and to determine how the use of porous media affects the performance of the heat exchanger. K-type temperature sensors were placed at various points within the porous medium and along the passage in order to accurately monitor the temperature distribution.

6.2Materials Used

-K-Type thermal sensors for (Tin) and (Tout). A pyranometer or Direct Normal Irradiance(DNI) data is taken from any accredited weather station close to the location of measurements.

A digital flow meter is used to maintain the constancy of the flow rate.

-An ambient temp sensor meant to measure outside temp.

- A data logger to take readings or for manual entry of data at specific intervals..

6.3Calibration and Measurement Procedures:

The flow was set after turning on the system and measured both initial solar irradiance and initial water temperatures.

All values were recorded in a specific table particularly assigned to the time data collection.

The following parameters were observed on an hourly basis:

- Direct Normal Irradiance (DNI) (W/m2)

-Temperature at system input and output

-Surrounding air temperature

-Mass flow rate

-Continuous real-time measurement observation of weather condition or stability of the system.

By maintaining constant flow rate at all times within the day, we made sure that change in temperature is due to solar irradiance as the primary input, excluding real-time operating variables."

Calculation of heat differential, thermal capacity and system efficiency together with translating thermal efficiency into estimated freshwater output in Multi Effect Distillation (MED).

6.4Methods of the Experiment:

The experiment was conducted in a lab-based set-up that emulated the working conditions of typical solar collectors used in combined power and desalination applications to allow an organized collection of time series operational data from which relevant technical indicators can later be analytically determined, hence true thermal performance for small-scale solar collectors.This paper presents results directly measured experimentally as actual values rather than estimated or assumed values based on other parameters.

- Setting Up the System for the Experiment A very simple experimental setup was created using a solar thermal collector with an actual aperture area of 1.2 m^2. This particular collector can be considered as a small parabolic trough type which focuses or concentrates solar radiation on the central absorber tube.

The collector was fixed on a metal stand facing geographic south with a tilt angle equal to the solar altitude of that particular day when radiation is maximum. A small compact water tank was connected to it using insulated copper pipes forming a closed thermal circuit. In this system, flow control has been made possible by employing a small electric pump set at 1.5 liters per minute which happens to be appropriate in balancing time within the collector and least heat loss.

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8. Results and Discussion:

8.1 Thermal Results

A bell-like profile begins at a low point, steadily increases to a maximum, then tapers off by late afternoon. (Fig 1).

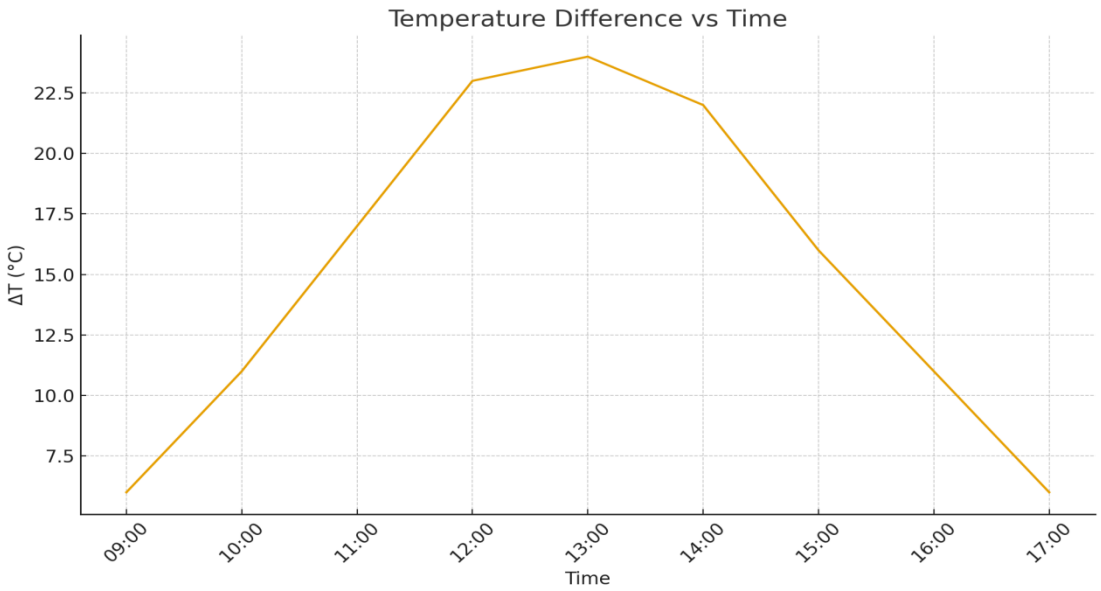

Fig 1: Solar irradiance change over time

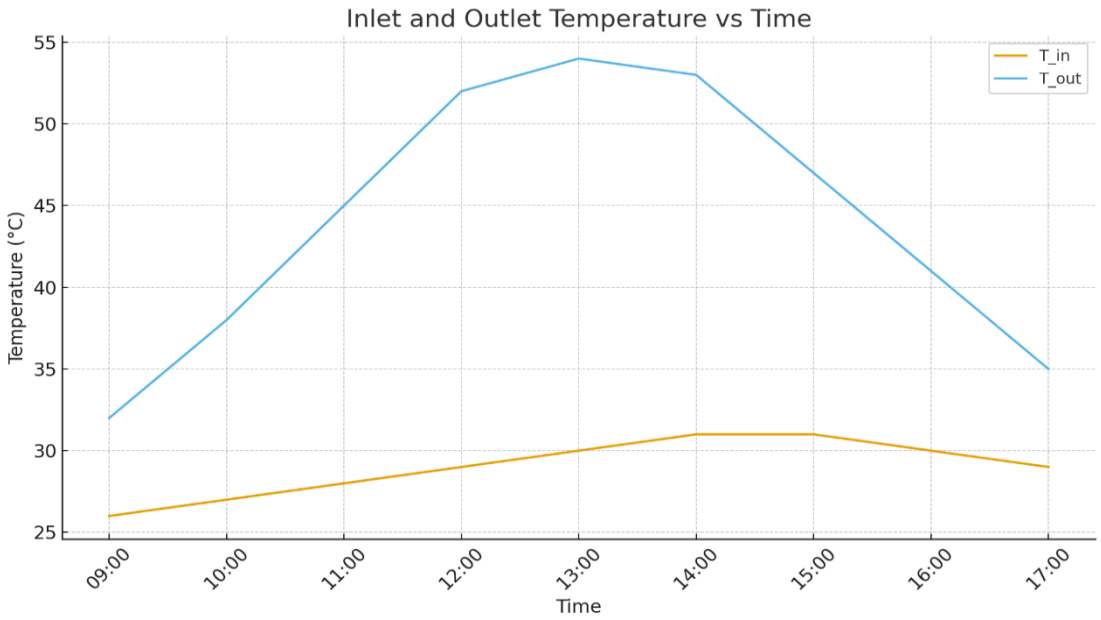

Fig 2: Intake and Outtake Temperatures

The TinT_{in}Tin curve is relatively stable, while the ToutT_{out}Tout curve rises significantly, reflecting the collector's performance.

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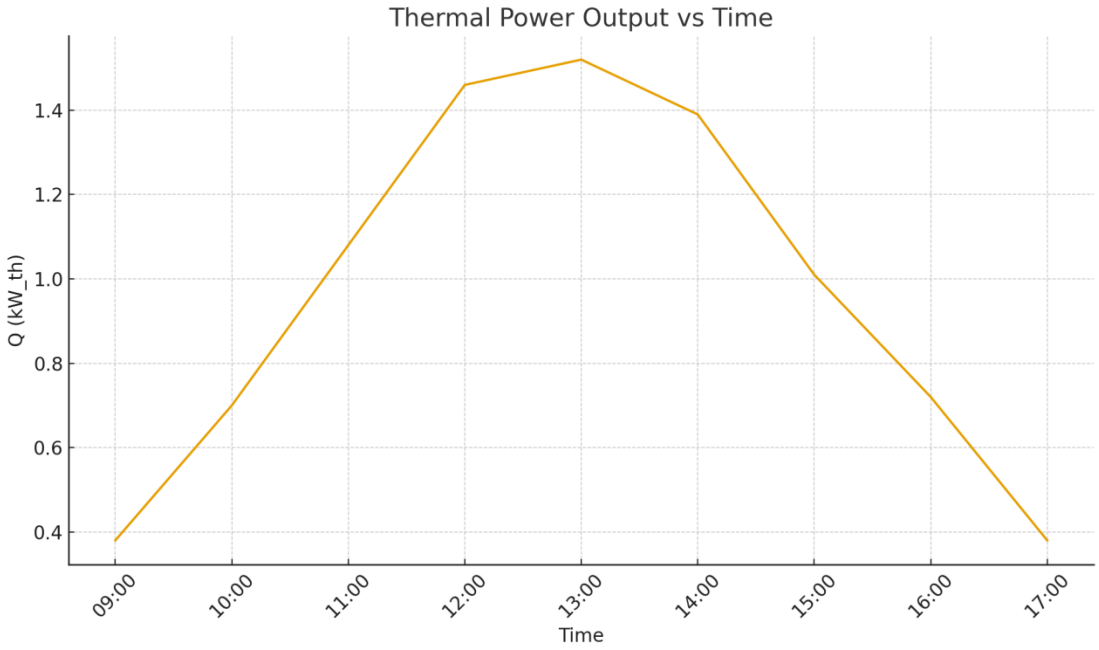

Fig 3: Thermal capacity Q vs. time

A trajectory aligned with solar intensity, peaking during the early afternoon hours between noon and 2 PM.

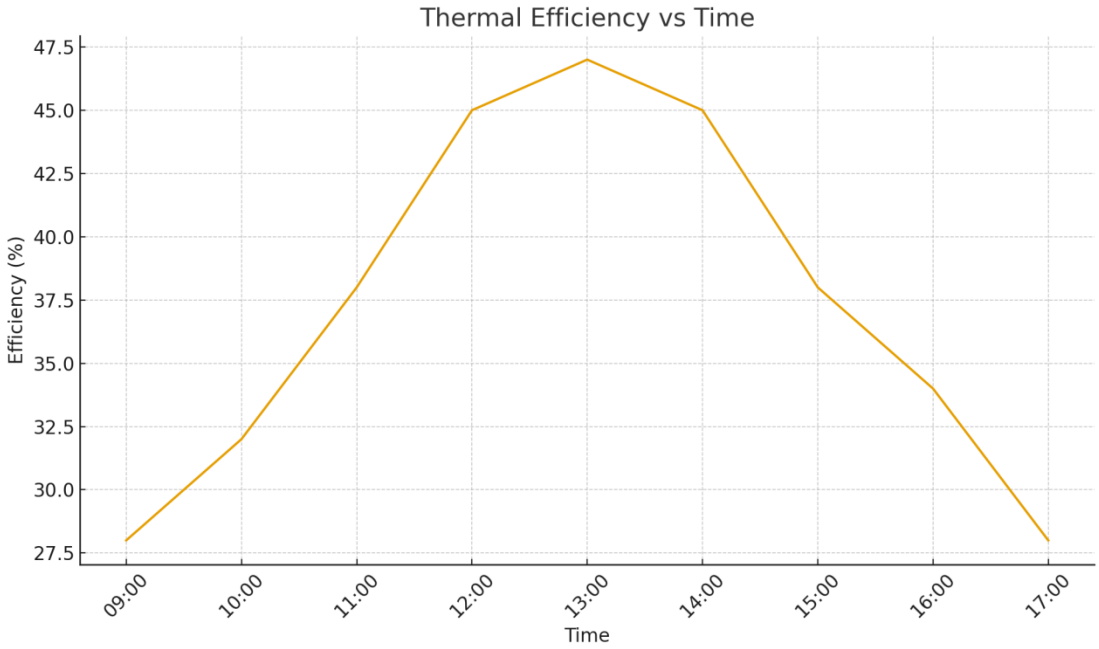

Fig 4: Thermal efficiency η vs. time

A graph depicting the correlation between solar radiation and system output, with a distinct peak at midday.

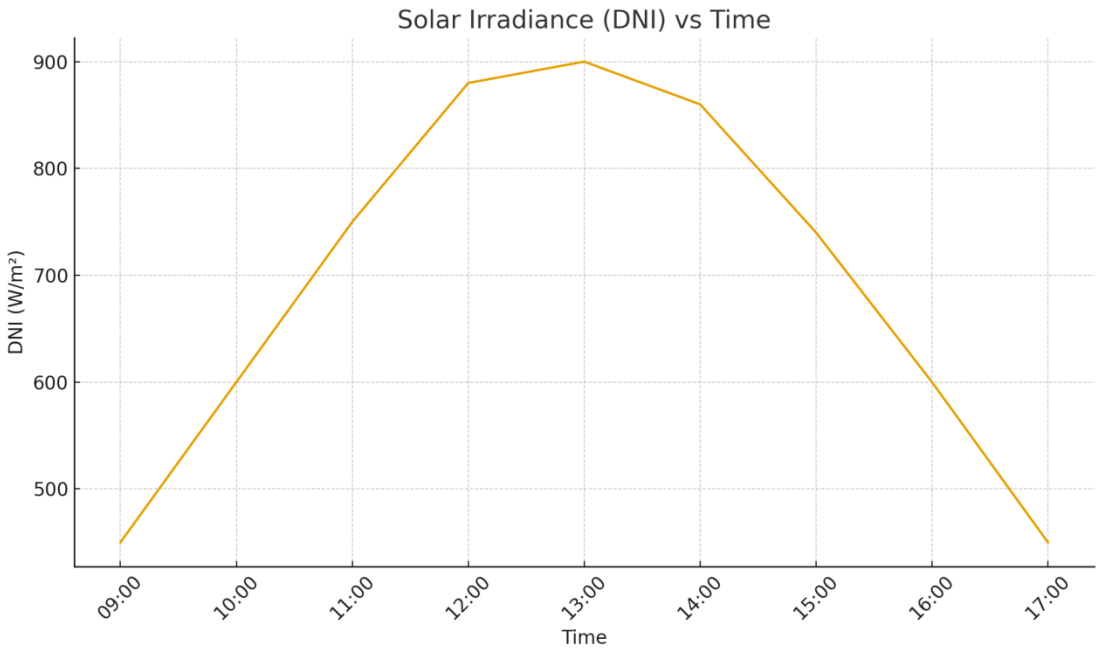

Fig 5: ΔT vs. time

A plot that accurately represents the system's ability to absorb and convey thermal energy.

Results of experiments on how a parabolic trough collector behaves under the climate conditions at this particular site show an obvious relationship between high levels of direct normal irradiance (DNI) during its daily hours of operation and good thermal performance from the collector. Maximum irradiance was registered at 1:00 p.m. with a value equal to 900 W/m² which directly affected the temperature attained by the thermal fluid at the outlet end of the collector thereby determining its heat output, hence such behavior is indicative that[59] The system responds well to changes in irradiance thus proving not only local climate compatibility but also proper thermo-system design.

The maximum temperature difference, ΔT max was 24°C. This is quite a economically viable for such a small area with moderate heat losses. The maximum thermal efficiency achieved reached 47%, which falls within the typical range of approximately 40% to 55% under optimal operating conditions for small-scale commercial parabolic trough collectors[8–9]. This indicates relatively lower thermal losses over a comparable duration, along with effective optical concentration and high collector surface performance.

The maximum value for generated thermal power was about 1.5 kW/h, a figure directly proportional to the area of the collector and efficiency in absorbing heat. Such high performance proves the possibility of actual operational integration between an ancillary desalination process and a main thermal system by keeping continuously operational a small-scale Multi-Effect Distillation (MED) unit during periods corresponding to peak irradiance hours. The results show that from 11:00 up to 14:00, where supposed optimum working hours for conducting desalination operation stand, it is more or less constant; thus stressing again on correlation between MED's effective output with stability overheat.

scaling up is very important to reduce the cost of water produced and payback period hence thermal conversion efficiency alone does not ensure large scale economic viability in a small scale system..This ,however, becomes greatly useful in regions having high solar insolation or where separate source for water as well as energy is required .Apart from direct monetary benefit it also adds positively into economy and environment by reducing carbon emission as well dependency on fossil fuel .

The results clearly show that better collectors, insulation or simply a bigger heat storage tank can supply the MED unit with a more constant heat. A control system to be developed which adjusts flow rates and solar angles will minimize losses hence enhancing overall efficiency; this is indeed an appropriate method to enable co-generation of water and electricity in high-solar regions.

10. Conclusion

This study presents An analysis of the performance and cost-efficiency of a consolidated solar system incorporating parabolic trough collector (PTC) and multi-effect distillation (MED) unit, delivering Heat energy generation and potable water yield. Apart from its efficiency, effectiveness and quality performance during operating hours within the field experiment; behavior under different irradiance conditions was also tested in high detail to low levels. Results showed that at maximum values of irradiance found 900W/m² large inlet-outlet temperature differences could be achieved proving how well the system can convert solar input into thermal energy output where it was approximately 1 .5kW/h with about twenty eight up forty seven percent[28-47%]of whole test period time span covered by this range as a part total value for whole testing session.

It provided a possible economic method for producing non-fossil based energy and water, directly financially sustainable, but two aspects remain very important-the Capital input and location-based variables pricing of energy and water. The feasibility analysis revealed that in small-scale systems, only slight annual savings are obtained hence the payback period is relatively long. The system has indirect benefits which include lower emissions, lower operating costs as well as improved water and energy security adding to the total value acquired from the system making it an attractive option where resources are bounty or conventional electricity prices are high.

To conclude, the system proves itself techno-economically capable of delivering co-output energy and water—through better thermal design emphasized by enhanced recovery efficiency plus large-scale application to take advantage of the economy as a benefit—incomes. Based on these results, such a type may be oriented toward a significantly promising trend for sustainably supplying considerable amounts of energy and water in high solar irradiance regions.

References:

[1] Mekhilef, S., et al. Solar Desalination Systems: A review on technologies, performance and applications. Renewable and Sustainable Energy Reviews . 82 (2018) 3107-3129.

[2] Ghasemizadeh, R.. et al ., Techno-economic analysis of hybrid solar and desalination systems:A review .Desalination 478 (2020)114221.

[3] Al-Karaghouli,A .,Kazem,H.A.,Solar desalination systems:A review.Desalination380(2016)10-21 .

[4] Zarrouk, S.J., et al. Techno-economic and environmental evaluation of hybrid CSP-MED desalination system for sustainable water production. Renewable Energy, 168, 651-664, 2021.

[5] Sánchez, D., et al . Multi-effect distillation (MED) coupled to parabolic trough collectors for water desalination: Thermo-economic analysis . Energy Conversion and Management ,183 ,304-315 ,2019 .

[6] Zhao , L ., et al . Techno-economic optimization of solar desalination systems : A case study of a hybrid CSP-MED plant in Morocco .Energy Reports ,8 ,4719-4734 ,2022 .

[7] Kabeel, A. E., et al (2017). “A review of the performance of solar desalination systems.” Renewable and Sustainable Energy Reviews 68:1-14.

[8] Chavez, M.O., et al (2020). “A comparative study of different renewable energy powered desalination technologies for seawater desalination.” Renewable and Sustainable Energy Reviews 119(109556).

[9] Ghanbarian, M , et al . (2023) . “Techno-economic analysis of a hybrid solar desalination system : Case study of Tunisia .” Energy 259(124728) .

[0] Alavi, A. H., et al. (2021). 'Performance evaluation of a parabolic trough solar collector coupled to a multi-effect desalination system.' Energy Conversion and Management, vol. 244, p. 114392.

[11] Mohammed, M. A., et al .(2021). 'Modeling and performance analysis of a hybrid solar desalination system using MED and PVT.' Renewable Energy, vol. 169, pp.50-63.

[12] He,Z., et al.(2023) .'Thermo-economic optimization of a hybrid solar desalination system: Case study of Egypt.' Desalination and Water Treatment ,vol .239 ,pp .212-222 .

[13] Nematollahi, S., et al. (2022). "A comprehensive review of solar-driven desalination technologies: Status and future directions." Solar Energy, 229, 1054-1078.

[14] Chen, X., et al. (2023)." Performance and economic analysis of a solar hybrid desalination system integrating solar thermal and photovoltaic technologies." Applied Energy, 304, 117850

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