Hybrid tubular solar systems: Thermoeconomic and environmental analysis of atmospheric water harvesting and electricity generation

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Introduction

Hybrid tubular solar systems are considered a promising approach to solving this problem, as they enable both water harvesting and electricity generation simultaneously. To evaluate the efficiency of such systems, it is important to comprehensively study their thermodynamic and exergetic characteristics, as well as their economic and environmental aspects. This paper examines the thermoeconomic and environmental efficiency of next-generation hybrid tubular solar systems and addresses the optimization of their design parameters.

Research methodology

This study is focused on the thermoeconomic and environmental assessment of hybrid tubular solar systems designed for atmospheric water harvesting and electricity generation. First, the geometric parameters, material properties, and operating conditions of tubular solar collectors are modeled. Heat and mass transfer processes within the system are analyzed using numerical simulation methods, including MATLAB software. Energy efficiency is evaluated through exergy analysis, comparing energy losses and useful energy output during system operation. The simulation results enable the assessment of system performance under various climatic conditions and operating regimes. The analysis also examines the balance and efficiency between water harvesting and electricity generation. In addition, the study provides insight into the ecological and economic potential of the technology in line with sustainable development goals. In the final stage, the proposed methodological approaches offer practical guidance for system design, optimization, and large-scale implementation [1].

Figure 1 schematically illustrates the numerical parameters of the hybrid tubular solar system and its main operating stages. It consists of several blocks representing specific components of the system.

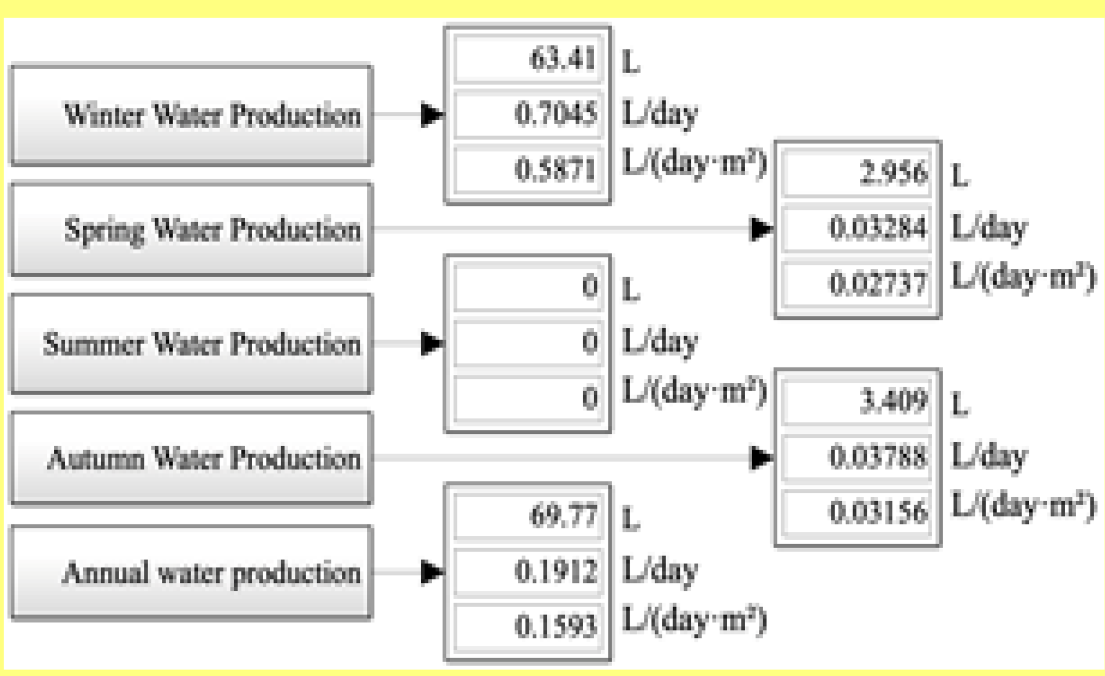

Fig. 1. Hybrid tubular solar system numerical indicators.

In Figure 2, the exergy of solar, water, and electric energy (i.e., the system's operational capacity) is shown over time, measured in joules (J). As can be seen from the graph, the exergy of solar energy has the highest value, approximately 1.73×106 J. This represents the total amount of energy supplied to the system from the solar radiation source. The exergy of electric energy (green line) is approximately 2.75×105 J, which accounts for about 16% of the solar energy exergy. The exergy of electric energy is also increasing, but its growth rate is significantly lower compared to that of solar energy [2].

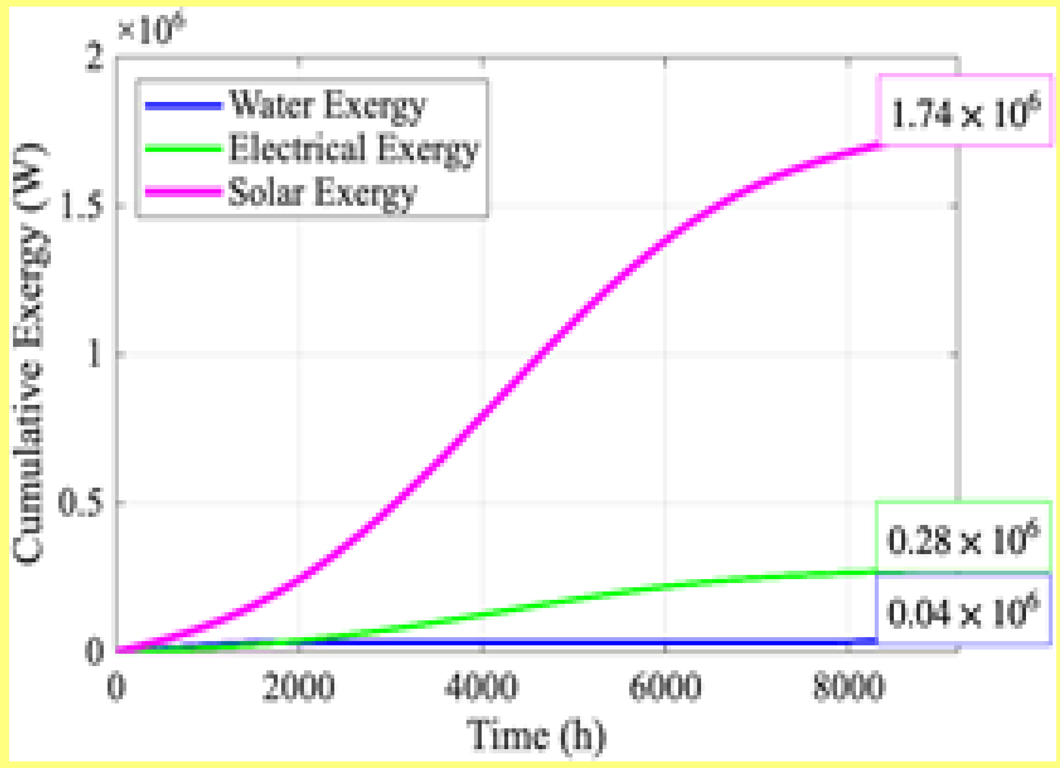

Fig. 2. Exergy of solar, water, and electric energy.

Simulation results

Table 1. System Paremeters

Component	Value	Efficiency
	J	%
Solar Exergy	1.73 × 106	100
Electrical Exergy	2.75 × 105	16.0
Water Exergy	4.3 × 104	2.5

Figure 3 presents the annual exergy efficiency indicator as a function of time in graphical form. This indicator describes how efficiently the system utilizes the total available energy. At the beginning of the graph, the efficiency is high; however, it gradually decreases over time.

By the end of the year, the efficiency reaches approximately 18%, meaning that the system is able to convert about 18% of the total received energy into useful exergy over the annual period. This value can be considered an average indicator of the system's energy conversion efficiency.

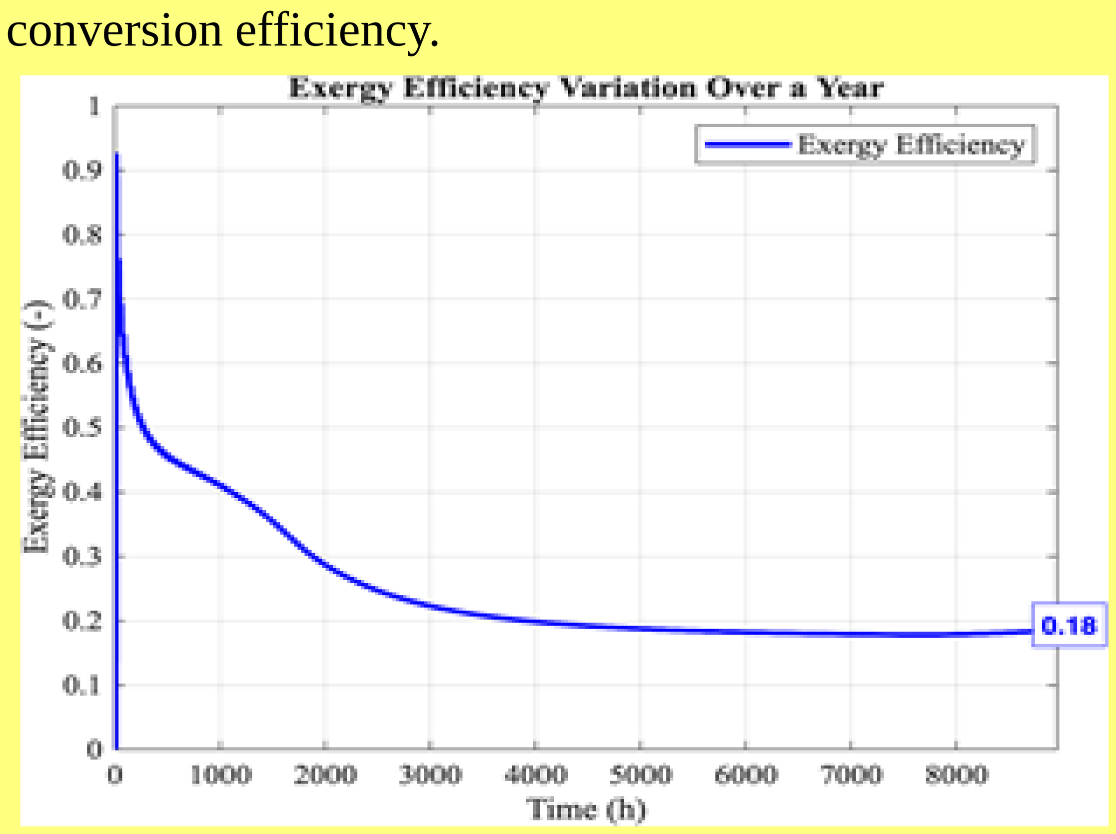

Fig. 3. Annual exergy efficiency indicator over time graph.

Results and discussion

The exergy efficiency shows a decreasing trend over time, eventually stabilizing at approximately 18%. This behavior is attributed to system stabilization and irreversible losses.

Key observations include:

- High initial efficiency due to optimal solar conditions;
- Gradual decline due to thermal losses;
- Steady-state performance under long-term operation.

The water harvesting subsystem exhibits lower efficiency compared to electricity generation, indicating potential for improvement in condensation technology.

Conclusions

The results of this study show that the exergy potential of solar energy plays a crucial role as the system's primary energy source. The exergy indicators of electricity generation and water harvesting processes determine the overall system efficiency; however, it was found that the energy efficiency of the water harvesting component is relatively low. Hybrid tubular solar systems contribute to reducing water scarcity and to the efficient utilization of renewable energy sources. Their design and optimization enable the integration of energy and water resources while providing environmental and economic benefits. The large-scale implementation of such systems can support effective engineering solutions aimed at addressing water and energy shortages. Thus, hybrid tubular solar energy systems are considered an important tool for achieving sustainable development goals, and the study results provide a basis for developing practical recommendations and roadmaps for real-world applications.

References

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