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Research Article

Numerical Study of a Simple Double-Slope Solar Distiller: A Sustainable and Economical Alternative

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ABSTRACT

Introduction: Faced with population growth, increasing needs for drinking water, and the scarcity of water resources in many regions of the world, the search for alternative and sustainable solutions for water production is becoming an urgent necessity. Among these solutions, solar distillation stands out as a simple, ecological, and economically viable technique, particularly for arid and isolated areas where access to fresh water is limited.

Objectives: Our work is part of a modeling and numerical analysis approach to the thermal performance of a simple double-slope solar distiller. The main objective is to evaluate the thermal behavior of the water and the absorber in this system, highlighting the effects of the configuration on the efficiency of the distillation process and, more specifically, on the quantity of water recovered.

Methods: The method chosen in our work is based on 3D geometric modeling using SolidWorks software, then integrated into the COMSOL Multiphysics simulation environment, which allows for multiphysics analysis of heat and moisture transfer phenomena. This numerical approach provides a detailed view of temperature evolution and a better understanding of the influence of the distiller's simple double-slope structure on the system's energy efficiency.

Results: In this study, we used COMSOL Multiphysics software to simulate and analyze the fundamental physical phenomena within a simple, double-slope solar still. We focused particularly on studying heat transfer in the water and the absorber, neglecting other areas of the system. The still under study is a simple, static system with no water flow; the water remains stationary in the basin. This configuration allowed for a more direct study of heat transfer between the different parts of the still (absorber and water). This simplicity facilitated the analysis of the thermal behavior and the evaluation of the device's energy performance. The numerical results confirm the system's efficient thermal operation, which is physically confirmed by the effective conversion of solar energy into heat, thus promoting water evaporation. Even when stationary, the water heats up, generating steam that then condenses to form distilled water. This process is primarily due to heat transfer by conduction, natural convection, and radiation within the device.

Conclusions: This work is part of the development of sustainable solutions for producing drinking water from solar energy. Through a numerical approach combining geometric modeling in SolidWorks and multiphysics simulation in COMSOL Multiphysics, we studied the thermal behavior of a simple configuration: a simple double-slope solar still. We investigated the variation of several parameters over the course of the tests. In conclusion, this numerical study makes a significant contribution to the understanding of thermal phenomena in solar stills. It also provides a solid foundation for the design, optimization, and construction of experimental prototypes, within the framework of promoting renewable, economical, and sustainable technologies in the field of water treatment and drinking water supply in regions currently suffering from water scarcity due to pollution, climate change, overpopulation, and the misuse of resources. A large part of the planet lacks water, a resource essential to life.

Keywords: drinking water, solar distillation, numerical analysis, solar still .

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INTRODUCTION

The shortage of drinking water and the depletion of natural resources, due to both drought and the overexploitation of groundwater, represent a major challenge threatening life in many regions. It is therefore essential to find and produce drinking water from other natural sources. In several areas affected by this shortage, brackish water resources, or even seawater with a certain salinity, are nevertheless available nearby. Desalination of this water by solar distillation is a method widely used in arid regions, whether on the scale of a village or even a household. Solar distillation makes it possible to produce drinking water from these non-potable sources by harnessing an abundant and free resource: solar energy [1].

This technology is based on fundamental thermodynamic principles, notably heat transfer and phase change (evaporation-condensation), which are at the heart of the operation of solar distillers. Solar energy is the energy provided by the sun through its radiation, either directly or diffusely through the atmosphere. On Earth, solar energy is the source of the water cycle and wind. This means that the raw material is the sun. It falls into the category of renewable energies since it is considered inexhaustible. It is also said to be 100% green energy because its production emits very little CO_2. It is also the source of all energy on Earth [2].

Solar distillation has been used for centuries, and various solar distiller designs have been developed, including greenhouse models, the type in our study. These models have the advantage of being simple, easy to manufacture, robust, and inexpensive, making them the most widely used.

Today, numerical simulation has become an indispensable element in the fields of science and engineering. It allows us to understand and model the operation of real systems, and a wide range of numerical tools are available. It relies on the implementation of theoretical models using various mathematical tools, including the finite element technique. Numerical simulation allows us to study the operation and properties of a modeled system, as well as predict its evolution. Based on this context, a 3D model of a simple, double-slope solar distiller was created to accurately represent the system's physical configuration. This model will be used later in COMSOL Multiphysics to simulate heat transfer and evaluate distilled water production yield [3].

The model created in SolidWorks is ready to be exported to COMSOL Multiphysics for numerical analysis. The next steps will include material assignment, defining thermal boundary conditions, and applying heat transfer modules to simulate the distiller's behavior under solar radiation. Experimental data will serve as a database to validate the simulation. The objective of this simulation is to understand the temperature distribution among the different components of the system, in order to evaluate the distiller's thermal performance and explore potential optimization strategies. Due to the challenges encountered during the simulation, each domain (liquid, solid) was studied separately to ensure numerical stability and the accuracy of the results [4].

OBJECTIVES

Our work is based on the implementation of theoretical models using various mathematical tools, including the finite element technique. Numerical simulation allows us to study the operation and properties of a modeled system, as well as predict its evolution. Based on this context, a 3D model of a simple, double-slope solar distiller was created to accurately represent the system's physical configuration. This model will be used later in COMSOL Multiphysics to simulate heat transfer and evaluate distilled water production yield [5].

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METHODS

The solar distiller model used comprises a lower tank for tap water, topped by two inclined glass panes forming a sloping roof, allowing for the condensation of water vapor. A base structure supports the entire assembly, and a channel is provided at the base of the glass panes for collecting the distilled water. The inclination of the glass panes promotes the gravity flow of droplets towards the lateral collectors [7].

A numerical study was conducted to evaluate the thermal performance of a simple, double-sloped solar distiller, based on simulations performed using COMSOL Multiphysics software. The following methodology was adopted: After launching COMSOL Multiphysics, we accessed the model configuration wizard. In this wizard, we opted for 3D modeling, deemed suitable for the needs of our study. Once the modeling wizard is launched, a new window opens, displaying all the physical phenomena that the software can simulate [8]. We then selected the one that best corresponded to the problem of our study. After selecting the appropriate physical phenomenon, we moved on to the geometry definition stage. COMSOL Multiphysics software has extensive features for creating and modifying geometries. In our case, the geometric modeling was done in SOLIDWORKS and then imported into COMSOL Multiphysics for use in the simulation. We selected the appropriate materials from the software's database, or added them manually if they were not available. Next, we assigned each material to the different parts of the geometry. After defining the materials and boundary conditions, we began the meshing stage. COMSOL Multiphysics provides automatic and semi-automatic meshing tools adapted to 1D, 2D, and 3D geometries. The user can adjust the mesh parameters to achieve the desired resolution. In our case, we opted for a triangular mesh, known for its ability to provide better numerical results. This step discretizes the continuous domain into a finite set of elements, thus facilitating subsequent numerical calculations [9].

RESULTS

In this part of our work, we will present the results obtained from the numerical modeling of a simple, double-slope solar still using COMSOL Multiphysics software. This study aims to analyze the temperature evolution of the absorber and the water to better understand the thermal behavior within the still. The COMSOL platform allowed us to accurately simulate heat transfer phenomena, enabling us to study the system's thermal performance and evaluate the impact of the design on the efficiency of the solar distillation process [10].

This study of simple solar stills requires a precise definition of the thermophysical properties of the materials and fluids used (water and a black-painted sheet steel absorber). The numerical simulations are based on initial temperatures observed experimentally in May 2025: for the simple still, the water is at 20°C and the absorber at 22°C. These values reflect actual ambient conditions and improve the representation of thermal behavior in the numerical model. Furthermore, a heat flux of 700 W/m² was applied to the glazed walls to simulate the effect of incident solar radiation on the system. The physical properties of the materials and fluids used in COMSOL Multiphysics are summarized in the following table1.

Table 1: Physical properties of materials and fluids

Fluid / Material	Thermal conductivity (W/m·K)	Density (kg/m³)	Heat capacity (J/kg·K)	Dynamic viscosity (Pa·s)
Water	0.6	1000	4180	0.001
Steel (absorber)	44.5	7850	475	/

The study area is visualized in Figure 1.

Area 1 represents the water zone, where heat absorption and temperature rise occur.

Area 2 represents the absorber zone.

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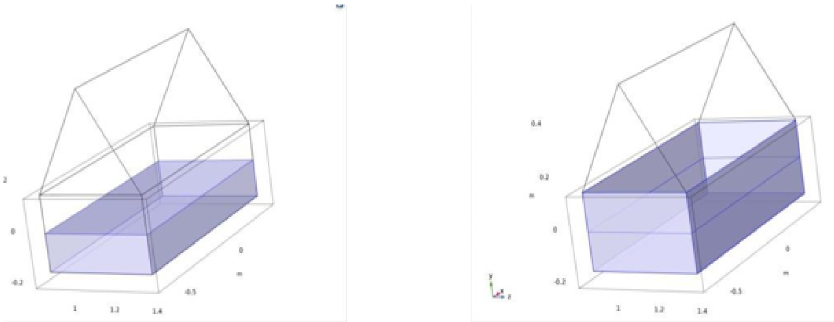

Area 1 "The water zone" Area 2 "The absorber zone"

Figure 1 : study *area*

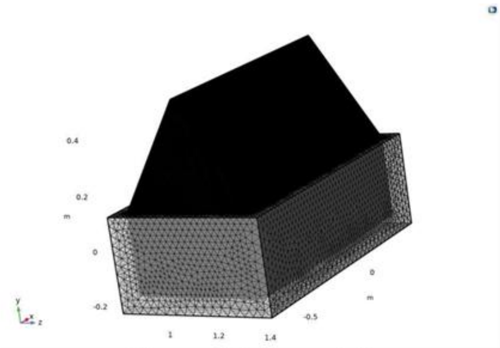

Figure 2*:* Mesh generated

The mesh [11]: The distiller used in this study has a specific geometry. Since our main objective is to analyze the temperature evolution at the water and absorber levels, we limited the model to the areas strictly necessary for our analysis in order to reduce computational complexity. We selected a finer mesh element size, shown in Figure 2, which allows for greater accuracy in critical areas, particularly at the interfaces between the water and the absorber. This refinement improves the quality of the results while maintaining an acceptable compromise between numerical accuracy and computation time.

DISCUSSION

The objective of this simulation is to understand the temperature distribution among the different components of the system, in order to evaluate the thermal performance of the distiller and to consider potential optimization strategies. Due to the difficulties encountered during the simulation, each domain (liquid, solid) was studied separately to ensure numerical stability and the accuracy of the results [12].

Figure 3 shows the temperature distribution; we note that as we get closer to the glass, the temperature increases rapidly and reaches a significant value, confirming the heat exchange inside the distiller.

Figure 4 illustrates the evolution of the absorber's temperature over a period of 9 hours, or 540 minutes. A regular and progressive increase in temperature is observed, rising from approximately 21 °C to over 54 °C. This constant rise indicates continuous absorption of solar energy by the absorber, which then transfers this heat to the water in contact with it.

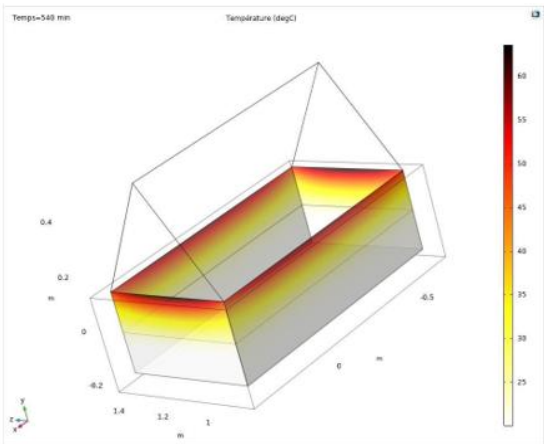

Figure 3: Thermal distribution of the absorber illustrated in 3D contours

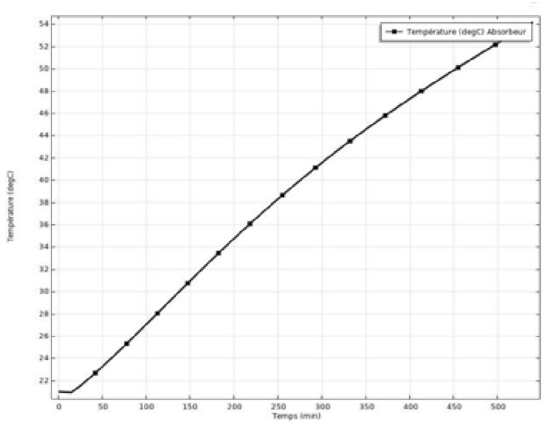

Figure 4: Temporal evolution of the absorber temperature.

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Although the system is closed, the small amount of residual air, as it warms up, contributes to heat transfer by convection and facilitates the transport of water vapor. This thermal interaction of the air plays a key role in the overall efficiency of the condensation process [13].

Figures 5 and 6 illustrate the gradual increase in water temperature in a simple solar still over a 9-hour period. The temperature rises from 20°C to 29°C, with a constant and steady increase, demonstrating a consistent temperature rise. This temperature increase is due to the absorption of solar radiation by the still's walls, which then transfer the heat to the water[14].

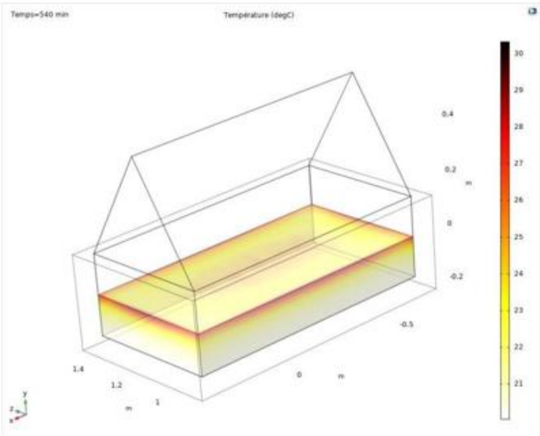

Figure 5: *Thermal distribution of water illustrated in 3D contours.*

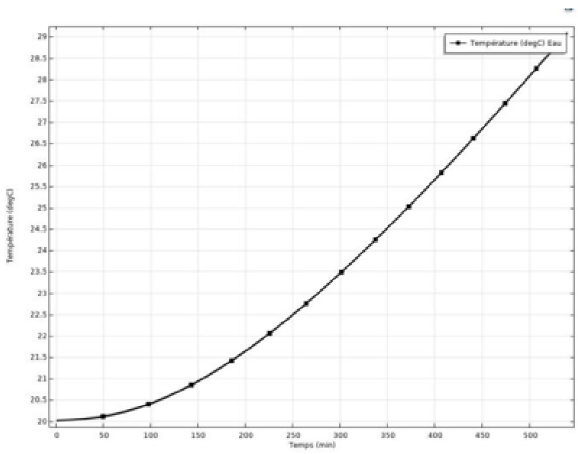

Figure 6: Temporal evolution of water temperature.

In conclusion, the study focused primarily on the temperature evolution of the water and the absorber in the simple double-slope distiller to evaluate its thermal efficiency. The results show that the distiller can reach high temperatures in both the water and the absorber, indicating improved heat absorption and retention capacity. This enhanced performance is explained by its simple structure, which promotes more efficient heat transfer and optimized use of incident solar energy [15].

This numerical study highlights the advantages of the design's nature for improving overall thermal efficiency and, consequently, distilled water production. However, this performance gain must be weighed against practical considerations such as manufacturing complexity, material costs, and adaptability to local climatic conditions [16].

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