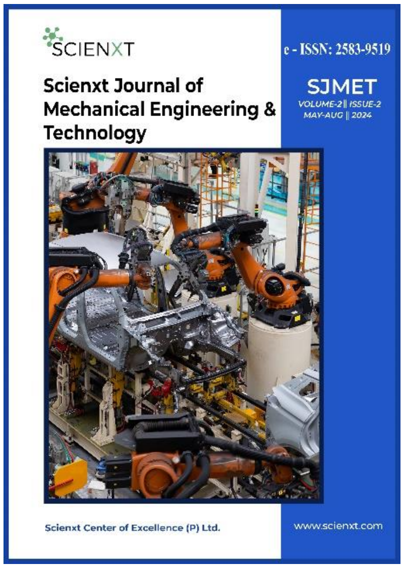

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Investigating novel approaches to improve the productivity of solar stills: a study on transport parameters and design optimization

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Abstract:

The solar still, operating on solar desalination principles, offers a solution to the challenge of obtaining potable water without relying on high-grade energy sources. Particularly valuable in remote regions with limited access to electrical power, solar stills have the potential to provide fresh water. However, their productivity in producing drinkable water is hindered by various factors. To address this issue, it is essential to investigate the modeling and transport parameters for designing more efficient solar stills.This study presents a multi-phase, three-dimensional Computational Fluid Dynamics (CFD) model of a single slope solar still. The model enables the simulation of temperatures at different points within the still. Comparisons between simulation results and experimental data demonstrate good agreement. Additionally, the study explores the impact of basin water depth on distillation yield. Interestingly, it is found that basin water depth has minimal effect on solar still productivity. For instance, reducing the initial basin water quantity from 20 liters to 10 liters resulted in a mere 5.13% increase in distillate output.

Keywords:

Solar still, desalination, Multiphase, CFD model

1. Introduction:

Contamination of water poses a significant challenge in India, impacting various aspects of human life such as health and environment. This contamination can arise from different sources including chemical, biological, and waste materials. Addressing this issue, the current study is dedicated to water purification and the removal of contaminants. Technological advancements in this field can lead to the production of water that meets health and environmental standards. Additionally, industries reliant on potable water can benefit from the conversion of polluted water into usable water, thereby fulfilling their need for suitable raw materials.

2. Solar distillation:

The World Health Organization estimates that more than one billion people lack access to purified drinking water, with the majority residing in rural areas. The challenges of low population density and remote locations make it impractical to implement traditional clean water solutions in these regions. Conventional desalination processes, such as reverse osmosis, multi-stage evaporation, and electrodialysis, are energy-intensive and not viable in remote areas. However, integrating renewable energy sources with desalination processes offers a solution to this problem. Given the high solar insolation in remote regions, solar energy presents a promising opportunity as an energy source for water desalination. Currently, only 1% of desalinated water is produced using renewable energy sources. Extensive research and development efforts have been undertaken to explore sustainable and feasible methods for producing drinking water using renewable energy. Utilizing solar energy in water desalination emerges as the most promising and cost-effective approach to providing potable water in remote areas. Solar energy is abundant and readily available in remote villages, making it an ideal solution for addressing the water scarcity issue in these regions.

3. Working principle of solar still:

In its simplest form, a solar still consists of an airtight insulated basin containing impure water and covered with a transparent material. Typically, the basin is constructed of galvanized iron sheet (GI-sheet), while the top cover is made of transparent glass or plastic. The glass cover is inclined, and a collecting tray is positioned at the base to gather the distilled output.

The working principle of a solar still mirrors the natural hydrological cycle. Solar radiation passes through the transparent cover, striking the inner surface of the basin. This inner surface is often blackened to enhance radiation absorption. As a result, the saline water in the basin heats up and begins to evaporate. The vapors rise, leaving behind salt and impurities. Upon reaching the inclined glass cover, the vapor condenses on the inner surface, and the condensed water flows down the collecting channel due to gravity. The distilled water collected in the channel is then retrieved for direct use.

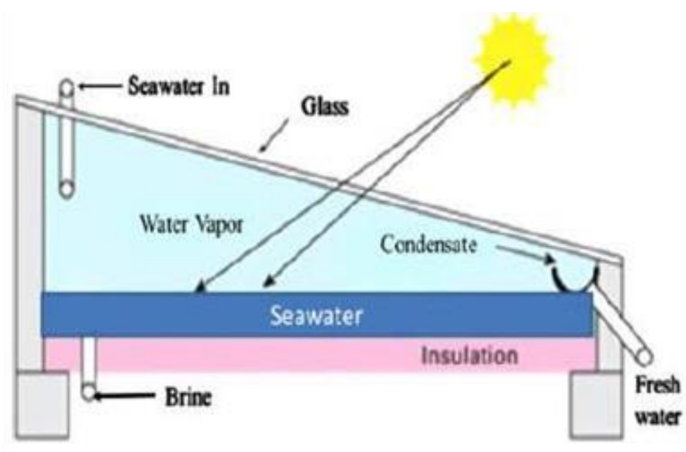

Figure. 1: Working of solar still

Solar stills offer an appealing solution for producing potable water in remote regions, with several key advantages:

- Being a low-cost device, solar stills can be fabricated using readily available materials.
- The design of solar stills is straightforward, allowing for easy construction by inhabitants of remote villages.
- Operation of solar stills is environmentally friendly, generating no pollution, and necessitates minimal maintenance.

- Construction and operation of solar stills do not require skilled labor, further enhancing their accessibility and usability in remote areas.

4. Geometric modeling of solar still:

The initial stage of conducting a Computational Fluid Dynamics (CFD) analysis involves generating a geometric model of the problem domain according to the design requirements. ANSYS Workbench offers Design Modeler as a design tool for developing these geometric models. Design Modeler offers a range of commands for creating both 2-D and 3-D shapes. Utilizing Design Modeler, the geometric model of the solar still was constructed. Fig. 2 illustrates the geometric model of the solar still.

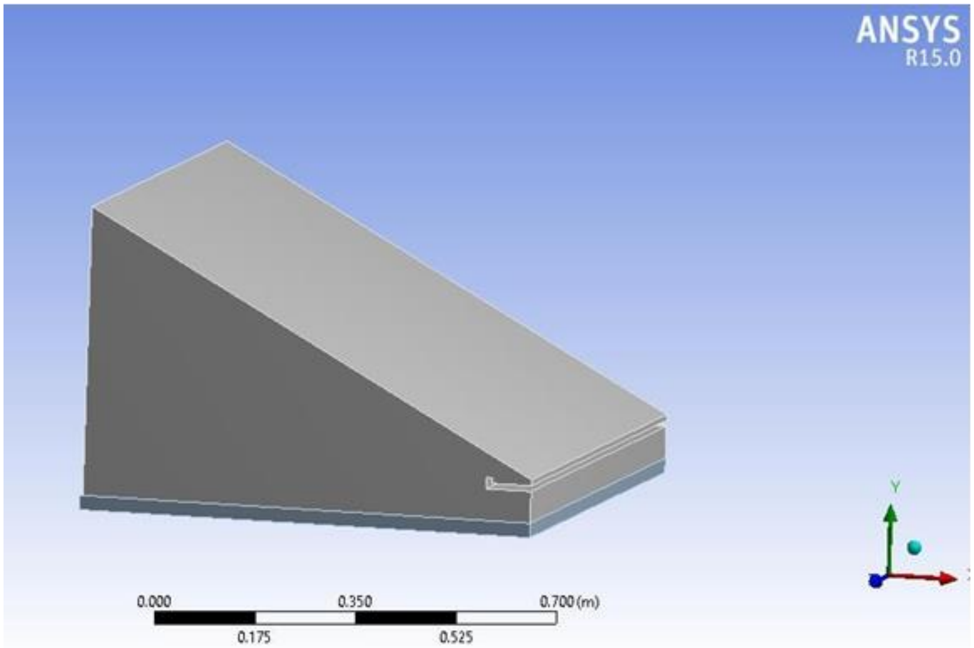

Figure. 2: The geometric model of Solar Still

5. Meshing of the domain:

After creating the geometric model, the subsequent step in the CFD analysis involves generating the mesh for the computational domain. During mesh generation, the problem domain is divided into numerous small cells. Meshing was conducted using hexahedral elements, chosen due to the predominantly rectangular surfaces of the solar still geometry. As the solar still geometry lacks curved surfaces, hexahedral meshing is well-suited and can deliver accurate results within a reasonable computation time. Fig. 3 depicts the meshing of the computational domain in a 3-D view. The total number of elements in the meshed domain is 100,229, which is deemed adequate considering the complexity of the problem at hand.

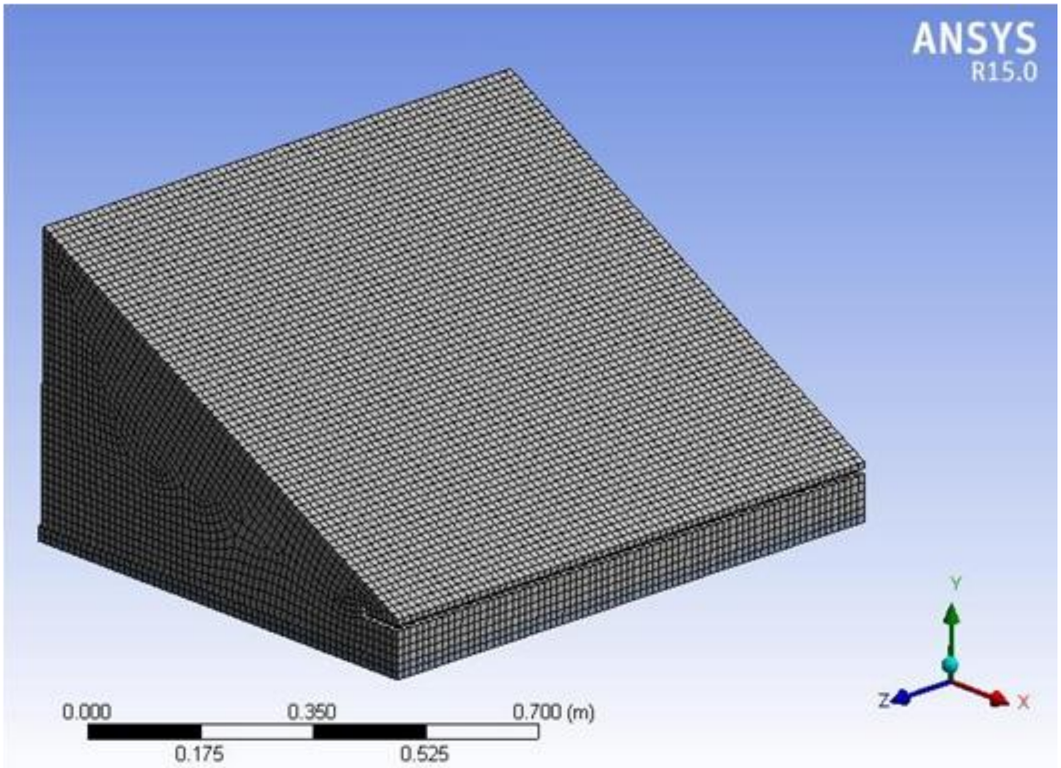

Figure. 3: Meshing of the computational domain

6. Temperature profiles:

In the case of a solar still, the temperatures reached by the glass cover, water in the basin, and the interior of the still are crucial for the distillation process. Generally, the amount of distilled water produced by a solar still relies on the temperature difference between the water in the basin and the glass cover. Temperature contours within the solar still are depicted on the X-Y plane passing through the center of the still and parallel to its side walls. Temperature profiles for the interior and glass temperatures are displayed at various time intervals. A common temperature range from 314 K to 360 K was selected for the temperature contours to ensure appropriate representation.

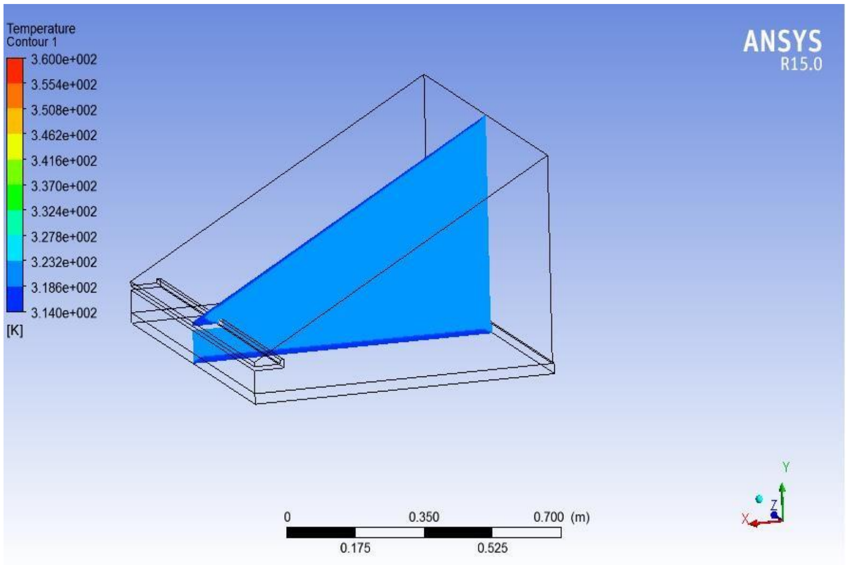

Figure. 4: Contour of interior temperature at 09:00 hrs

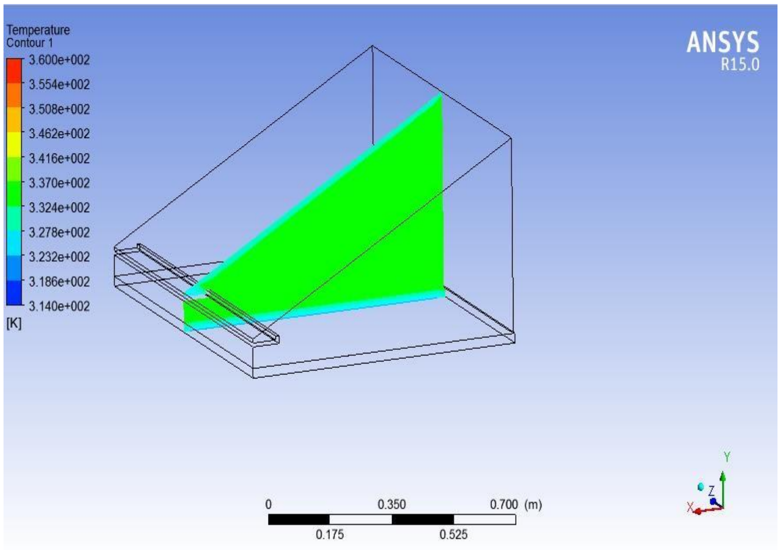

Figure. 5: Contour of interior temperature at 10:00 hrs

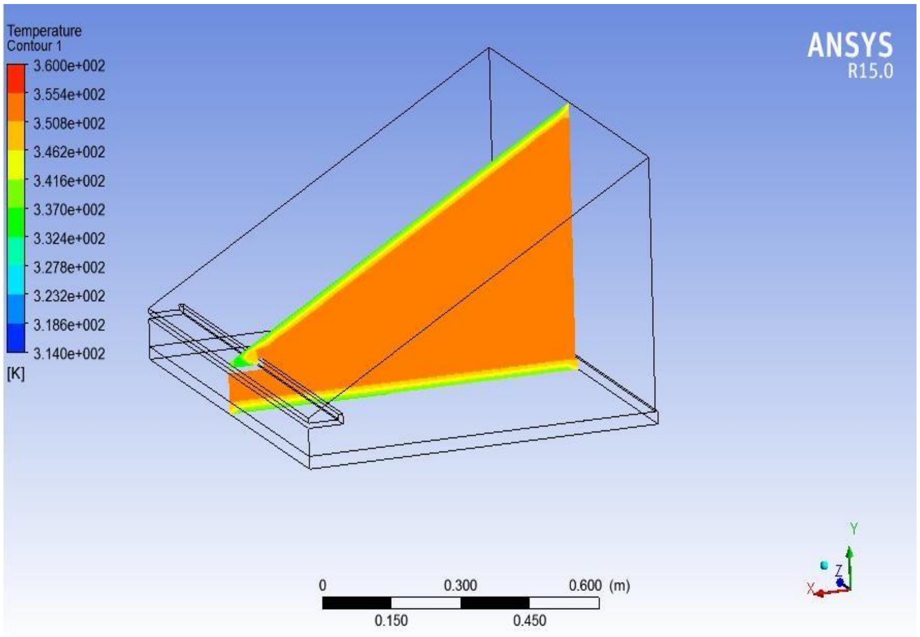

Figure. 6: contour of Interior temperature at 12:00 hrs

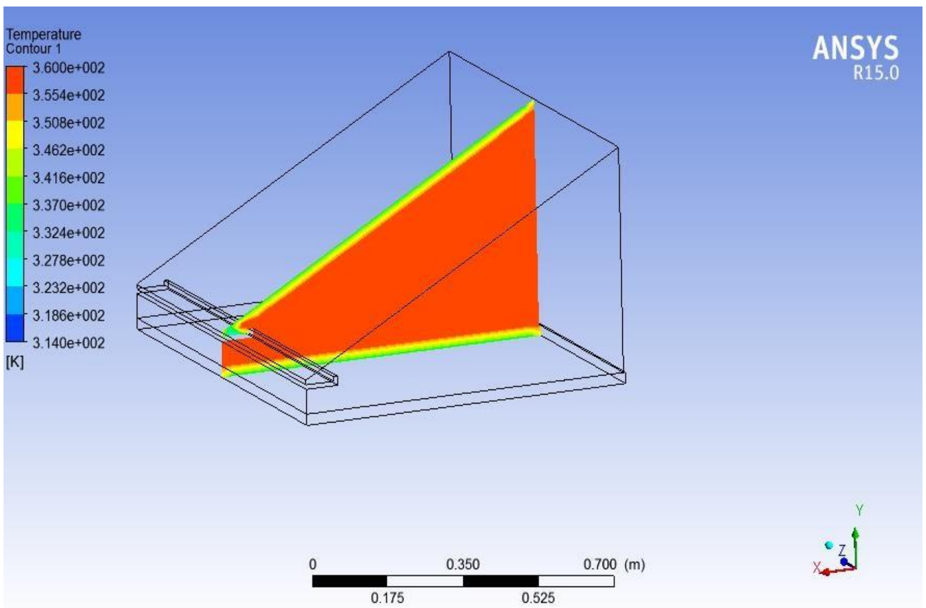

Figure. 7: contour of Interior temperature at 14:00 hrs

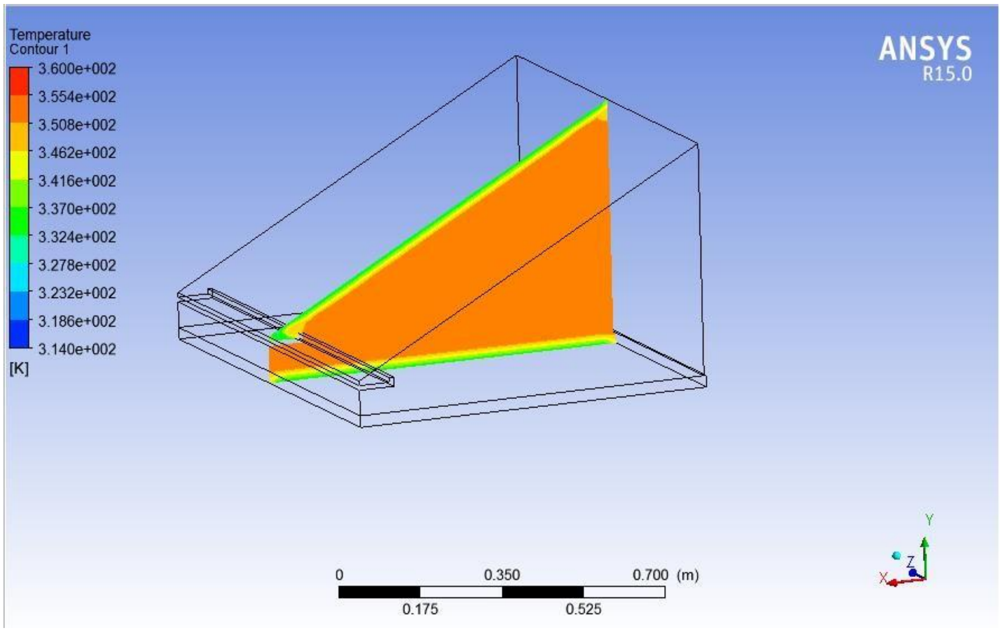

Figure. 8: contour of Interior temperature at 16:00 hrs

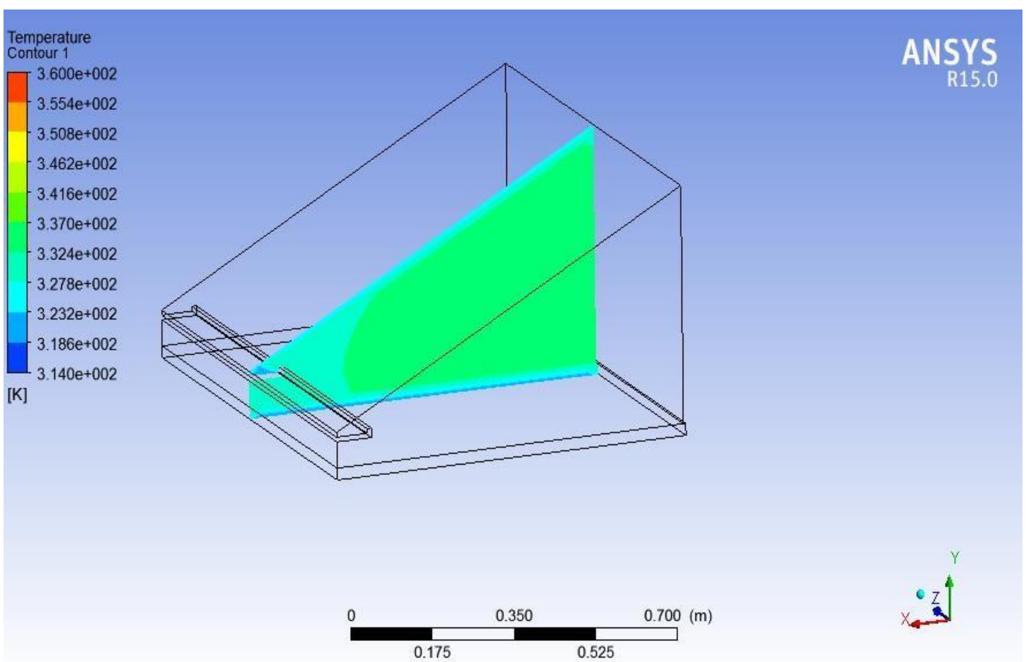

Figure. 9: contour of Interior temperature at 18:00 hrs

The contours depicting the interior temperature of the solar still reveal the following observations:

- As solar radiation reaches the basin, the temperature of the water begins to rise, leading to evaporation over time. This evaporation results in the formation of vapor within the still, consequently increasing the interior temperature. The contours of the interior temperature illustrate a gradual rise in temperature within the solar still over time.
- The temperature inside the solar still correlates directly with the intensity of solar radiation. It steadily increases until around 13:00 hrs and then gradually decreases. Essentially, the interior temperature of the still mirrors the pattern of solar radiation incidence on the glass cover.
- Examination of the interior temperature contours indicates a nearly uniform temperature distribution within the still. This uniformity arises as, after one hour of operation, the hot vapors occupy most of the space within the still.

7. Conclusions:

The primary aim of this study was to develop a 3-D computational fluid dynamics (CFD) model of a single slope passive solar still and to validate the simulation results against experimental data. Initially, the 3-D geometric model of the solar still was constructed in ANSYS Workbench using design modeler, followed by selecting appropriate models to represent the physical phenomena occurring within the solar still. The key findings of the study are summarized as follows:

- The developed CFD model successfully predicts the temperature distribution within the solar still, with simulated interior temperatures aligning closely with experimental measurements.
- The temperature of the glass cover exhibits a similar trend to that of solar radiation, peaking at approximately 337 K around 13:00 hrs before gradually declining due to diminishing solar intensity.

- Distillate water output rate and evaporative heat transfer coefficient were calculated using Dunkle's model based on CFD data. The comparison between simulated and experimental data demonstrates good agreement for distillate yield.

- The impact of water depth in the basin on distillate yield was examined through simulations conducted at three different water quantities: 10 liters, 15 liters, and 20 liters. While there was a marginal increase in distillate output with decreasing basin water depth, the overall change was not significant, with a marginal increase of approximately 6% observed.

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