Solar Still Simulation Algorithm

Fatima BELMEHDI

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1 Introduction

This program is designed to model the thermal behavior of solar stills (SS) using a simplified thermal model based on the Lumped Capacitance Method. This method assumes that the entire system can be represented as a single lumped mass with a uniform temperature at any given time, eliminating internal temperature gradients. The program focuses on four geometric configurations of solar stills and provides detailed thermal analysis for each component.

Figure 1: Stepped solar still

References

Refer to this article:F. Belmehdi, S. Otmani, M. Taha Janan, Enhanced mathematical modeling for optimizing solar stills with AI exploitation, Desalination 595 (2025) https://doi.org/10.1016/j.desal.2024.118303

2 Theoretical Background

2.1 Lumped Capacitance Method

The thermal model of a solar still is simplified using the **Lumped Capacitance Method**, a heat transfer approach that models the transient temperature response of a homogeneous object subjected to temperature or heat flux changes. This method assumes that the entire system can be represented as a single lumped mass with a uniform temperature at any instant.

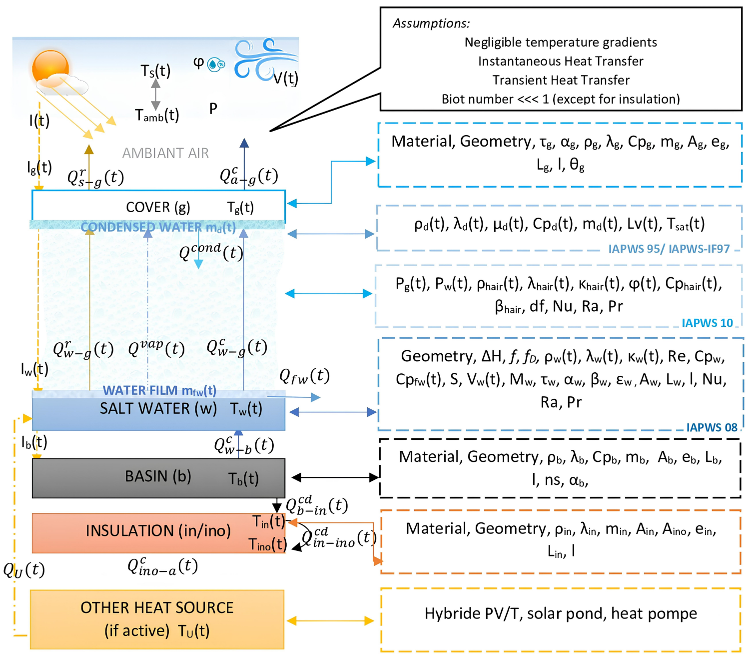

Figure 2: Simplification of thermal model for solar stills

2.2 Mathematical Model

The solar still is modeled as three main components: 1. Transparent Cover 2. Saline Water 3. Basin with Insulation

The energy balance equations for each component k are expressed as:

$$C_{p_i} m_i \frac{dT_i}{dt} = I_i + \sum_{j=1}^{n} Q_{ij}^{mode} \quad (Equation 1)$$

(1)

Where: - C_{p_i}: Specific heat capacity of component i - m_i: Mass of component i - T_i: Temperature of component i - I_i: Incident solar radiation on component i - Q_{ij}^{mode}: Heat transfer between components i and j via different modes (radiation, convection, conduction, etc.)

2.3 Energy Balance Equations for Each Component

1. Transparent Cover:

$$C_{p_g} m_g \frac{dT_g}{dt} = I_g - Q^r_{s-g} - Q^c_{a-g} - Q^{cond} + Q^r_{w-g} + Q^c_{w-g} + Q^{vap} \quad (Equation 2)$$

2. Saline Water:

$$C_{p_w} m_w \frac{dT_w}{dt} = I_w - Q^r_{w-g} - Q^c_{w-g} - Q^{vap} + Q^c_{w-b} + Q_{fw} \quad (Equation 3)$$

3. Basin:

$$C_{p_b} m_b \frac{dT_b}{dt} = I_b - Q^c_{w-b} - Q^{cd}_{b-in} \quad (Equation 4)$$

2.4 Numerical Solution

The system of differential equations is solved numerically using the Runge-Kutta 4th Order (RK4) method. The equations are simplified into the following form:

$$\frac{dT_k(t)}{dt} = a_k T_k^4 + b_k T_k + c_k \quad (Equation 5)$$

Where: - a_k, b_k, c_k: Parameters calculated for each component (cover, water, basin) based on material properties, geometry, and operating conditions.

2.5 Parameter Calculation

The parameters a, b, and c are calculated as follows:

1. For the Cover (g):

$$a_g = \frac{A_g h^r_{g-s} + A_w h^r_{g-w}}{M_g C_{p_g}} \quad (Equation 6)$$

$$b_g = \frac{A_g (h^c_{g-a} - h^{cond}) + A_w (h^c_{g-w} + h^{vap})}{M_g C_{p_g}} \quad (Equation 7)$$

$$c_g = \frac{A_g (h^c_{g-a} T_a - h^{cond} T_w) + A_w T_w (h^c_{g-w} + h^{vap}) + A_g h^r_{g-s} T_s^4 + I_g}{M_g C_{p_g}} \quad (Equation 8)$$

2. For the Water (w):

$$a_w = \frac{A_w h^r_{g-w}}{M_w C_{p_w}} \quad (Equation 9)$$

$$b_w = \frac{A_w (h^c_{g-w} + h^{vap}) + A_b h^c_{b-w} + Q_{fw}}{M_w C_{p_w}} \quad (Equation 10)$$

$$c_w = \frac{A_w T_g (h^c_{g-w} + h^{vap}) + A_b h^c_{b-w} T_b + A_w h^r_{g-w} T_g^4 + I_w + Q_{fw} T_a}{M_w C_{p_w}} \quad (Equation 11)$$

3. For the Basin (b):

$$a_b = 0 \quad (Equation 13)$$

$$b_b = \frac{A_b (h^c_{b-w} + h^{cd}_{b-in})}{M_b C_{p_b}} \quad (Equation 14)$$

$$c_b = \frac{A_b (h^c_{b-w} T_w + h^{cd}_{b-in} T_{in}) + I_b}{M_b C_{p_b}} \quad (Equation 15)$$

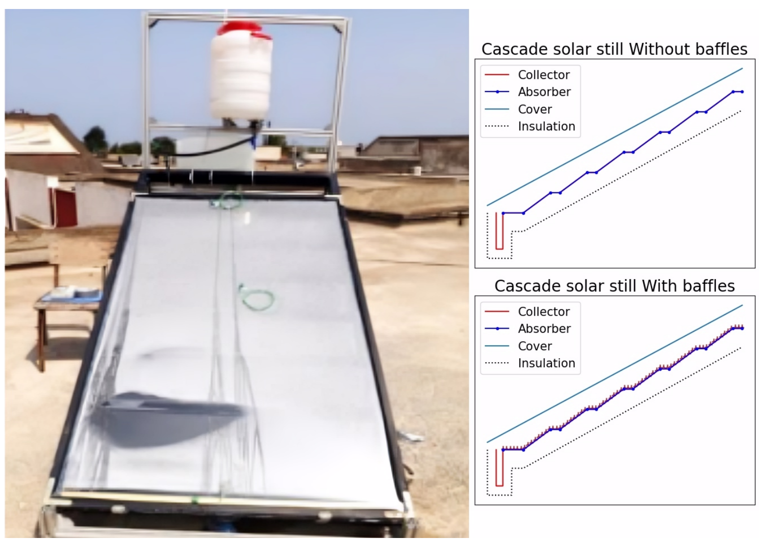

Figure 3: Cascade solar still (real device and visualization)

2.6 Program Features

2.6.1 Input Data

The program requires input data, which is provided via a predefined Excel file. This file includes: - Geometric parameters of the solar still - Meteorological and environmental conditions - Material properties (e.g., thermal conductivity, specific heat) - Salinity and total mass of the saline water

2.6.2 Thermodynamic Properties

The program calculates thermodynamic properties of fluids (saline water, distilled water, and water vapor) using equations of state from the International Association for the Properties of Water and Steam (IAPWS) iapws python documentation https://iapws.readthedocs.io/en/latest/ These properties include: - Specific heat capacity - Density - Saturation pressure - Viscosity

2.6.3 Heat Transfer Models

The program supports multiple heat transfer models, including: - Dunkle's model - Chen et al.'s model - Zheng Hongfei et al.'s model - Hollands et al.'s model

2.6.4 Output Results

The program provides the following outputs: - Visualization of the solar still geometry - Temperature profiles of the cover, water, and basin - Cumulative condensed water flow rate - Overall efficiency and performance of the solar still - Cost estimation

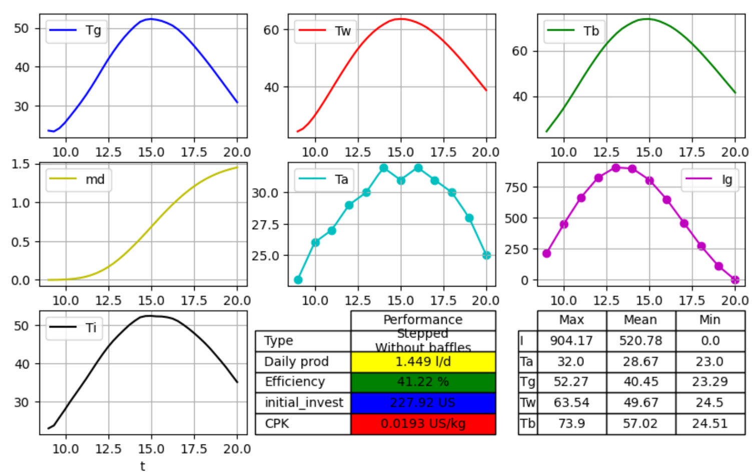

Figure 4: Numerical output of the software)

2.6.5 Error Analysis

The program includes an error analysis feature to compare experimental and numerical results. The error is calculated as:

$$Error = \sqrt{\frac{Err^2_{T_g^{av}} + Err^2_{T_w^{av}} + Err^2_{T_b^{av}} + \Delta T^2_{inst}}{T_{av}}} \quad (Equation 113)$$

Where: - $Err_{T_g^{av}}$: Average error for the glass cover - $Err_{T_w^{av}}$: Average error for the water - $Err_{T_b^{av}}$: Average error for the basin - ΔT_{inst}: Instrumental error

3 Conclusion

This program provides a robust and flexible tool for modeling solar stills with four geometric configurations. It integrates advanced numerical methods, thermodynamic calculations, and error analysis to ensure accurate and reliable results. The program is suitable for researchers and engineers working on solar desalination systems.