Abstract

The global energy crisis and environmental concerns have accelerated the shift toward renewable energy sources. As fossil fuels deplete and climate change worsens, cleaner alternatives have become essential. Renewable energy not only addresses ecological challenges but also supports economic growth and energy independence. Among these, solar power stands out as a sustainable option due to its abundance and cleanliness. Solar thermal systems utilize solar collectors to capture sunlight and convert it into thermal energy, using fluids like water or air for heating and power generation. Key components of a flat-plate collector include the absorber plate, fluid-carrying tubes, transparent cover, insulation, and casing, all designed for high efficiency in various applications.

Each category of solar collectors is designed for specific energy needs, chosen based on economic viability and climate. Enhancing the efficiency of these collectors is a key research area. The prominent Hottel-Whillier-Bliss (H-W-B) model, developed from earlier works in 1942, 1953, and 1959, is one-dimensional and follows a lumped formulation. While research has evaluated various parameters affecting collector performance, a comprehensive theoretical analysis is still needed. This PhD study aims to fill that gap by conducting a two-dimensional thermal analysis of flat-plate collectors to improve thermal performance through analytical and numerical modeling. It will examine heat transfer dynamics, fluid flow behavior, and efficiency improvements, focusing on their overall impact on system performance.

A study develops an approximate analytical method to calculate the two-dimensional temperature circulation in an absorber plate and validates it against finite-difference method results. The findings show excellent agreement, with deviations of less than 5%, confirming the model's reliability for practical use.

A study provides a closed-form solution for 2D heat transfer in absorber plates, accounting for nonlinear temperature variations at the plate-tube interface. The energy equation is solved analytically using the separation of variables method and validated with the finite difference method. Results show a strong correlation between both approaches, confirming the model's accuracy. This framework offers a reliable method for thermal evaluation of solar collector absorber plates.

A modified one-dimensional method using the trapezoidal rule is proposed for approximating two-dimensional analysis, with validation against the finite difference method showing good agreement. The classical one-dimensional model is inadequate for absorber plates, whereas the modified model aligns closely with the two-dimensional approach, offering a more straightforward, more efficient solution. This study enhances the accuracy of thermal analysis for absorber plates, aiding in the design and optimization of flat-plate solar collectors.

Analytical studies of solar flat-plate collectors typically use the classical Fourier heat conduction model, which assumes an infinite thermal wave propagation speed and a linear relationship between heat flux and the temperature gradient. This assumption conflicts with Einstein's relativity, even though it adheres to the second law of thermodynamics. To address this, the Cattaneo-Vernotte model introduces a finite thermal wave speed by incorporating a relaxation term, transforming the heat conduction equation from parabolic to hyperbolic. Previous research simplified this model by neglecting the time relaxation term. However, analyses that do include this term show that it reduces temperature circulation on the absorber plate.

In solar flat-plate collectors, the working fluid is crucial for heat transport. Nanofluids outperform conventional fluids like water, enhancing absorber plate performance and overall efficiency. A comprehensive thermodynamic analysis, including energy and exergy evaluations, identifies various losses, improving the efficiency of thermal systems. This research examines the energy and exergy of absorber plates in solar flat-plate collectors using nano-hybrid fluids containing CuO, MgO, and TiO_2 nanoparticles, providing insights into more efficient absorber plate models and improved thermal performance in solar thermal systems.