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A REVIEW OF ENHANCEMENTS IN ABSORBER PLATE GEOMETRY FOR SOLAR DESALINATION: EXPLORING INNOVATIONS AND FUTURE PROSPECTS

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ABSTRACT

In light of the ongoing global water scarcity crisis, solar desalination emerges as a promising solution by leveraging abundant yet saline water resources. However, challenges persist, particularly the low productivity of solar stills. A crucial aspect is the interaction between the absorber plate and saline water, where modifications to the absorber plate geometry are essential for boosting productivity. This article examines the effects of incorporating fins, using baffles, and adopting corrugated or stepped absorber plates. It explores how geometric parameters, including fins, baffles, steps, and corrugations, influence thermal resistance, heat distribution, and preheating time. Notably, fins demonstrate exceptional performance when the mass of saline water is constant, while corrugated designs are more effective for maintaining consistent water depth. The article concludes with a tabular summary of recent advancements in absorber plate geometry modifications, followed by a discussion of comparative studies, significant findings, and future research directions.

Keywords: Solar Desalination, Absorber Plate Geometry, Productivity Enhancement, Flat Plate Collector

1. INTRODUCTION

Solar desalination is an emerging technology that harnesses solar energy to convert saline water into fresh water, offering a sustainable solution to water scarcity. Among the critical components in this process is the absorber plate, whose geometry significantly influences the system's efficiency by enhancing heat transfer. Over the years, extensive research has been devoted to optimizing the design and material of absorber plates to maximize the solar energy absorption and heat distribution. This review aims to provide a comprehensive analysis of the advancements in absorber plate geometry, highlighting key innovations and their impact on the overall performance of solar desalination systems. By examining various design modifications, such as surface texturing, channel configurations, and material enhancements, the paper seeks to identify the most promising approaches for future applications. Furthermore, this review will discuss the challenges associated with integrating these enhancements into large-scale systems and offer insights into potential directions for future research. The goal is to provide researchers and engineers with a detailed understanding of current trends and future prospects in the development of absorber plates, thereby contributing to the advancement of efficient and sustainable solar desalination technologies.

The rising environmental crises come from negative emissions and pollution, affecting ecosystems and human well-being. The reliability of fossil fuels for energy generation is eclipsed by their impact to global warming and climate alteration, the outcome of extended and excessive consumption. Addressing these difficulties is vital to provide a sustainable future, mandating a move towards cleaner and renewable energy sources to limit the repercussions on the earth and public health [1]. China has introduced a plan to reach carbon peaking and carbon neutrality targets, focusing on five key objectives: establishing an eco-friendly, low-carbon, and circular economy; enhancing energy efficiency; raising the use of non-fossil energy; reducing CO2 emissions; and bolstering ecosystems' ability to store carbon. Solar energy is acknowledged as a clean energy source to assist these green, low-carbon, and circular economy aims. Various aspects effect solar energy absorption in distinct wavelength bands have been explored in Ref. [2]. Solar energy heating has become popular through major performance and structural advancements. It comes into two categories: the thermal system, which translates solar energy into heat energy, and the photovoltaic (PV) system, which converts solar energy into electricity [3]. Yet, solar intensity at night and on overcast days doesn't adequate to create the thermal energy needed for domestic hot water (DHW) generation. In fact, the unconverted solar energy raises the temperature of PV/T panels, which in turn affects their electrical conversion efficiency. [4-7]. To overcome these difficulties, photovoltaic thermal (PV/T) integrated the heat pump system was proposed to simultaneously fulfil the demand for the DHW supply and electricity production, such as a ground source heat pump driven by a PV system [8], a heat-pipe solar PV/T heat pump system [9], a solar-assisted dual-source multifunctional heat pump [10,11], a dual-use roll-bond-PVT heat pump system [12], a hybrid solar-assisted CO2 heat pump [13], liquid-based PV/T assisted heat pumps [14], the indirect expansion PV/T heat pump [15,16], the direct expansion solar-assisted SAHP system [17] and a novel roof-PV/T solar assisted heat pump system [18], etc. Previous study has also evaluated the performance of the PV/T integrated heat pump system [1,16,19-21] and demonstrated that it showed better performance and could stably work [22].

2. MATHEMATICAL MODEL AND EQUATION

2.1 Solar Radiation Model:

One of the fundamental equations in this field deals with the estimation of solar radiation incident on a flat plate collector. The most commonly used model for this is the **Hottel-Whillier-Bliss (HWB)** equation:

$I_t = I_0 \cdot \exp(-\tau \cdot X / \sin(\beta))$

Where:

- I_t is the solar radiation incident on the collector (W/m²).
- I_0 is the extraterrestrial solar radiation on a horizontal surface (W/m²), typically calculated using solar geometry equations.
- τ is the transmissivity factor, representing the optical efficiency of the cover or glazing.
- X is the thickness of the cover material (m).
- β is the tilt angle of the collector (degrees).

2.1 Collector Efficiency Model:

The efficiency of a flat plate collector is crucial in determining its performance. The efficiency model considers various losses, including heat losses and optical losses. The overall efficiency (η) can be expressed as:

$\eta = Q_c / A \cdot I_t$

Where:

- Q_c is the useful heat output from the collector (W).
- A is the area of the collector (m²).

The collector efficiency depends on parameters like the collector's heat removal factor (F_r), the collector heat loss coefficient (U_l), and the collector heat gain factor (F_{RUL}).

2.2 Energy Balance Equation:

The energy balance equation for a solar water heater relates the heat absorbed by the collector to the heat supplied to the water. It can be expressed as:

$Qc = A \cdot I_t \cdot \eta - U_l \cdot A \cdot (T_c - T_a)$

Where:

- Q_c is the useful heat output from the collector (W).
- A is the area of the collector (m²).
- I_t is the solar radiation incident on the collector (W/m²).
- η is the collector efficiency.
- U_l is the collector heat loss coefficient (W/(m²·K)).
- T_c is the collector's temperature (K).
- T_a is the ambient temperature (K).

These equations are fundamental in analysing and designing solar water heater systems with flat plate collectors. Researchers and engineers often use software tools like TRNSYS, SAM (System Advisor Model), or MATLAB to perform simulations and calculations involving these equations in practical applications. Feel free to use LaTeX or a similar tool to format these equations for your specific needs.

3. COMPUTATIONAL FLUID DYNAMICS (CFD)

3.2 Governing Equations

The governing equations for a CFD model of a solar water heater with flat plate collectors include the following:

3.2 Continuity Equations (Mass Conservation)

This equation describes how mass is conserved within the system.

$\partial \rho / \partial t + \nabla \cdot (\rho \mathbf{V}) = 0$

Where:

- ρ is the fluid density.

- **V** is the velocity vector.

3.3 Navier-Stokes Equations (Momentum Conservation):

These equations describe the conservation of momentum within the fluid.

$\partial(V\rho)/\partial t + \nabla\cdot(\rho VV) = -\nabla P + \nabla\cdot(\tau) + \rho g$

Where:

- P is the pressure.
- τ is the stress tensor.
- g is the gravitational acceleration vector.

3.4 Energy Equation:

This equation governs the temperature distribution within the system, taking into account heat transfer mechanisms.

$\partial(\rho E)/\partial t + \nabla\cdot(\rho EV) = \nabla\cdot(k\nabla T) + \rho V\cdot\nabla T + Q$

Where:

- E is the total energy per unit mass.
- k is the thermal conductivity.
- T is the temperature.
- Q represents heat sources or sinks.

3.5 Boundary Conditions

To complete the CFD model, you'll need to specify appropriate boundary conditions for the fluid flow, heat transfer, and radiation within the solar water heater system. This includes conditions at the inlet and outlet, as well as conditions for the flat plate collector, heat exchanger, and other components.

3.6 Turbulence Model

Turbulence models in Computational Fluid Dynamics (CFD) are used to simulate the behavior of turbulent flows, which are characterized by chaotic and swirling motion. These models provide a way to predict the distribution of turbulence properties within a fluid domain. One commonly used turbulence model is the Reynolds-Averaged Navier-Stokes (RANS) model. Here's an explanation of the RANS model with its key equations:

3.7 Reynolds Averaged Navier Stokes (RANS) Models:

The RANS model aims to predict the time-averaged flow properties, including velocity and pressure, as well as the turbulent properties, such as turbulence kinetic energy (k) and turbulent dissipation rate (ε). The key equations of the RANS model are the Reynolds-averaged Navier-Stokes equations, along with equations for turbulence quantities:

Reynolds-Averaged Navier-Stokes Equations (RANS Equations):

The Reynolds-averaged Navier-Stokes equations are based on the decomposition of flow variables into mean and fluctuating components. The equations for the mean velocity components (u, v, w) and pressure (P) are as follows:

- Continuity Equation (for incompressible flow):

$\nabla\cdot U = 0$

- Momentum Equations (for the x, y, and z directions):

$\partial(u)/\partial t + (u\cdot\nabla)u = -1/\rho(\nabla P) + \nu\nabla 2u - \partial(u'u')/\partial x - \partial(u'v')/\partial y - \partial(u'w')/\partial z + \partial(\tau ij)/\partial x$

(Similar equations for v and w)

Where:

- U=(u,v,w) is the mean velocity vector
- ρ is the fluid density
- ν is the kinematic viscosity
- P is the mean pressure
- u′u′, u′v′, u′w′, and τij represent the Reynolds stresses (turbulent components of the stress tensor), which are modelled based on turbulence models.

Turbulence Quantities Equations (k-ε Model):

In a k-ε turbulence model, two additional transport equations are solved to predict turbulence kinetic energy (k) and the turbulent dissipation rate (ε):

- Transport Equation for Turbulence Kinetic Energy (k):

∂(k)/ ∂t +(u⋅∇) k=∂/∂xj [(ν+νt) ∂k/∂xj] −ui′uj′ ∂ui/∂xj −ρϵ

- Transport Equation for Turbulent Dissipation Rate (ε):

∂(ϵ)/ ∂t +(u⋅∇) ϵ= ∂/∂xj [(ν+νt) ∂ϵ/∂xj] +C1ϵ/k [2ui′uj′ ∂k/∂xj] −C2ρϵ2/k

Where:

- νt is the turbulent viscosity, typically modelled as νt=Cμk2/ϵ
- C1 and C2 are model constants
- ui′uj′ represents the Reynolds stresses

4 CONCLUSION

Solar water heaters with flat plate collectors exemplify the integration of renewable energy technologies with sustainable heating solutions. These systems offer a viable route to decreasing dependence on fossil fuels, reducing environmental impact, and cutting energy costs. In this discussion, we've delved into the essential principles and components of these systems, along with key mathematical models and Computational Fluid Dynamics (CFD) considerations. Powered by the sun’s abundant energy, solar water heaters reflect a commitment to a greener and more sustainable future. The flat plate collector, a core element of these systems, demonstrates the effectiveness of simple yet efficient design. It is crucial in absorbing solar radiation and converting it into thermal energy, meeting everyday water heating needs with a minimal environmental footprint. The mathematical models associated with solar water heaters—including those related to solar radiation, collector efficiency, and energy balance—serve as the basis for understanding and enhancing system performance. These models enable accurate performance predictions under varying conditions, guiding engineering decisions to improve efficiency and reliability.

Furthermore, the development of CFD models for solar water heaters has expanded the scope of detailed analysis and optimization. By incorporating the Navier-Stokes equations, energy equations, and turbulence models, CFD simulations provide valuable insights into fluid flow patterns, temperature distributions, and system efficiency. This allows engineers to refine design parameters and boost overall performance.

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