CONSTRUCTAL LAW CONFERENCE – CLC2024
Design in Nature and Evolution
Romanian Academy, Bucharest, 10–11 October 2024

Proceedings of CLC2024
pp. 117–120

OPTIMIZING VOLUMETRIC SOLAR AIR RECEIVERS: NUMERICAL ANALYSIS OF POROSITY AND FLOW EFFECTS ON TEMPERATURE DISTRIBUTION

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Ceramic foams are promising as absorber materials for volumetric solar receivers (VSR) in concentrated solar thermal power (CSP) systems. The temperature distribution of the VSR is very important to ensure that it operates efficiently and steadily. This study aims to simulate and analyze the temperature distribution within a VSR considering both the solid and fluid phases. The modelling of the open-cell volumetric receiver employs combined volume-averaged equations, assuming the ceramic foam to possess isotropic and homogeneous properties. To assess the pressure-drop in the VSR a non-Darcian model is adopted. A local thermal non-equilibrium (LTNE) model is implemented to describe the energy equations for both the solid and fluid phases.

Additionally, the study considers the influence of solar radiation as a heat source on the solid phase. The heat transfer between the surfaces of the volumetric solar air receiver's struts is calculated using the P1 model. At the same time, a macroscopic approach is utilized to evaluate the thermal profile of the ceramic foam. This study also aims to assess the impact of the VSR's porosity and cell size variation on the outlet air temperature. Moreover, the flow scheme of the flowing air, concerning the incident of concentrated radiation, is considered.

Keywords: Volumetric solar receiver; Ceramic foam; Local thermal non-equilibrium model; Macroscopic approach; Thermal analysis**.**

1. INTRODUCTION

Continuous developments to reduce the greenhouse gas emissions by replacing the fossil fuel generation with cleaner energy sources. This can help meet the increasing energy demand of modern society while mitigating the effects of climate change and global warming [1]. The growing attention placed on renewable energy sources such as wind and solar has led to the development of new technologies. One of these is concentrated solar power [2], in which the thermal efficiency reaches 40% [3]. The open-cell volumetric receiver is a vital component of solar power tower technology. It is composed of a porous material that is heated by concentrated solar radiation [4]. The stability of the porous material, high concentration, and optics of the solar receiver are some technological obstacles that still need to be overcome [5]. Most of the research on open-cell volumetric receivers focused on ceramics due to their ability to endure higher temperatures [6,7]. Studies on the design and parameters of the porous solar receivers have been carried out to improve their performance [8]. Wu *et al*. [9] have studied the temperature distribution of the fluid and solid phases in volumetric solar receivers using the Local Thermal Non-Equilibrium approach. The study analyzed the effects of velocity, porosity, mean cell size, and the thermal conductivity of the solid phase on the temperature fields.

DOI: https://doi.org/10.59277/CLC/2024.30

The aim of the presented study to simulate and analyze the distribution of temperature within a volumetric solar air receiver that encompasses both solid and fluid phases. The modelling of the open-cell volumetric receiver employed the averaged-volume equations. It assumes that the ceramic foam possesses isotropic and homogeneous properties. A non-Darcian model is adopted to evaluate the pressure drop within the volumetric solar receiver. A local thermal non-equilibrium model is implemented to accurately describe the energy equations for both the solid and fluid phases.

Additionally, the study considers the impact of solar radiation as a heat source on the solid phase. The heat transfer occurring between the surfaces of the struts in the volumetric solar air receiver is calculated using the P1 model. At the same time, a macroscopic approach is employed to assess the thermal profile of the volumetric receiver. The primary focus of this study is to evaluate how variations in the porosity and cell size of the volumetric solar receiver impact the outlet air temperature with different air flow schemes relative to the incident concentrated radiation within the open-cell ceramic foam.

2. MATERIALS AND METHODS

A real volumetric solar receiver absorber can have different shapes, such as rectangles, hexagons, or other configurations. Experimental studies typically utilize cylindrical absorber samples. In numerical studies, the shape of the absorber can be easily adjusted. This study employed a bulk of cylindrical-shaped ceramic foam to compare with experimental data. The dimensions of the foam material, the physical model, and the coordinate system are presented in Fig. 1.

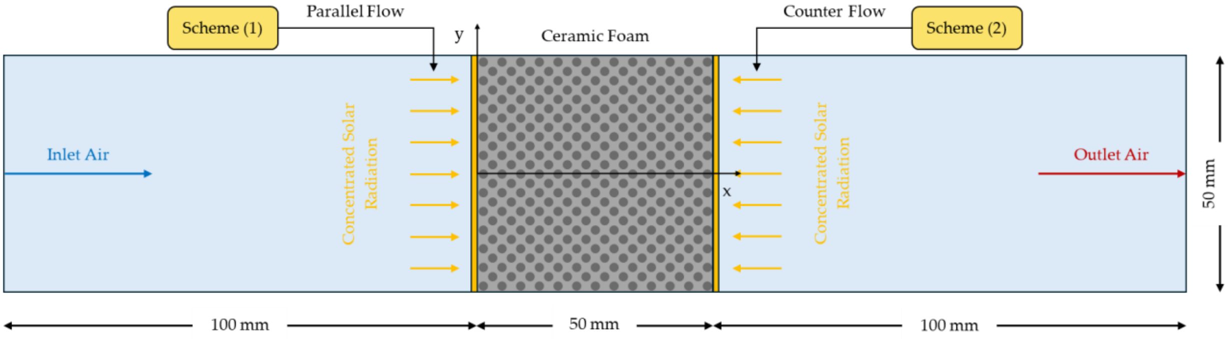


Fig. 1 – The sketch of the open-cell SiC volumetric solar receiver.

3. RESULTS AND DISCUSSION

Figure 2 illustrates the temperatures of the open-cell ceramic foam, both solid and fluid phases, along its axial line. The investigation reveals the thermal characteristics of the volumetric receiver under specific conditions. These include an inlet air velocity (u_d) of 1.08 m/s, a porosity (ϕ) of 0.8, and a mean cell size (d_c) of 1.5 mm. The preliminary findings were validated by comparing them to the findings of Wu *et al*. (T_s* and Tf*) [8]. The comparison demonstrated that any disparities between the temperatures predicted by the presented model and those of Wu *et al*.'s model can be ignored.

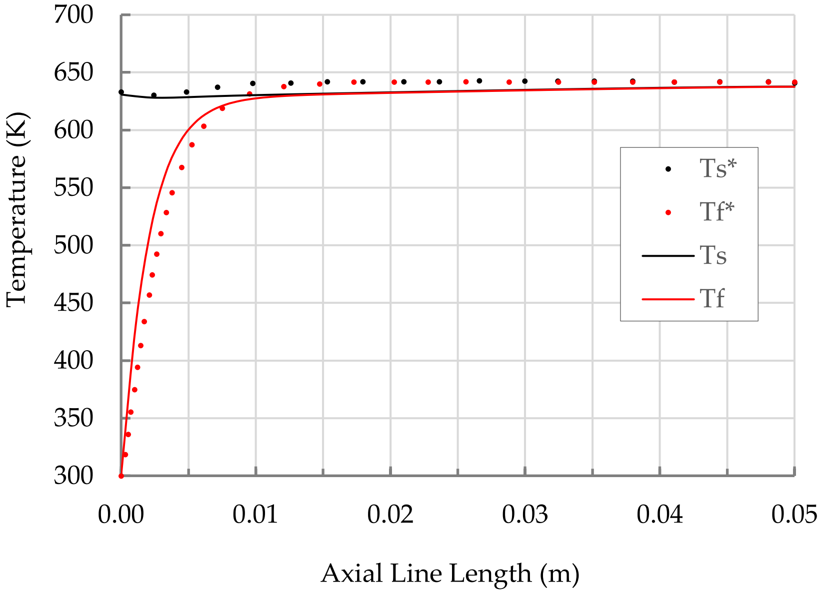
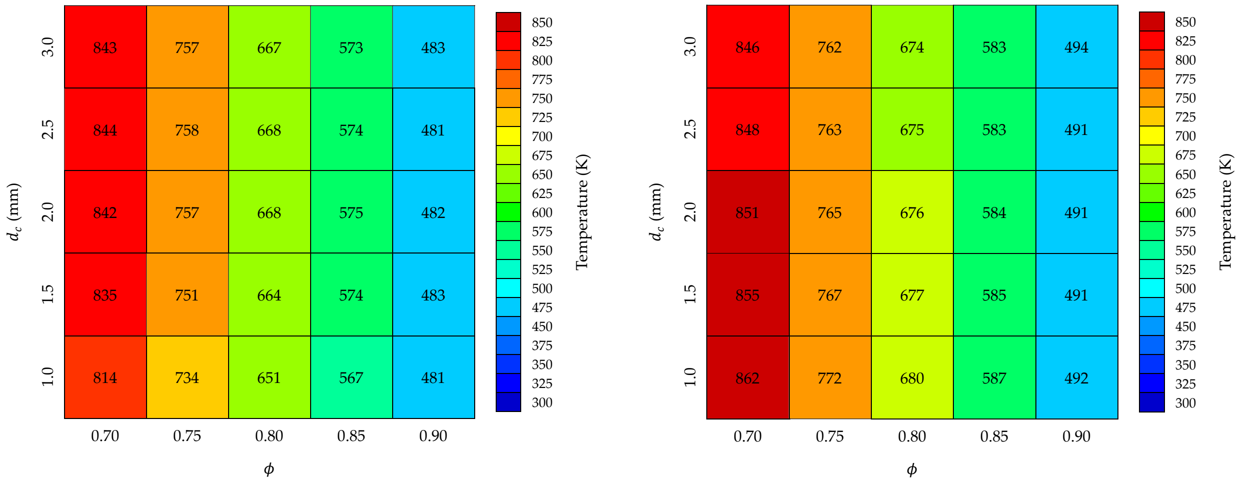


Fig. 2 – The solid and fluid temperatures along the axial line of the open-cell SiC volumetric solar receiver with u_d = 1.08 m/s, ϕ = 0.8 and d_c = 1.5 mm.

A parametric study on the arrangement of the ceramic foam's structure parameters has been evaluated. They consider parallel and counterflow schemes with different combinations of porosities and cell sizes to maximize the outlet air temperature. The porosity and cell size have varied from 0.70 to 0.90 and 1.0 mm to 3.0 mm, respectively. Figure 3 presents the outlet air temperature of (a) parallel and (b) counterflow schemes. The results reveal that the lower porosity and the higher cell size porous ceramic foam shows higher thermal performance within an outlet air temperature of 844 K for the parallel-flow scheme. However, the numerical results illustrate different tendencies for the counter-flow scheme where the lower porosity and the lower cell size porous ceramic foam show higher thermal performance within an outlet air temperature of 862 K.



d_c (mm)	0.70	0.75	0.80	0.85	0.90
3.0	843	757	667	573	483
2.5	844	758	668	574	481
2.0	842	757	668	575	482
1.5	835	751	664	574	483
1.0	814	734	651	567	481

ϕ

(a)

d_c (mm)	0.70	0.75	0.80	0.85	0.90
3.0	846	762	674	583	494
2.5	848	763	675	583	491
2.0	851	765	676	584	491
1.5	855	767	677	585	491
1.0	862	772	680	587	492

ϕ

(b)

Fig. 3 – The outlet air temperature of **(a)** parallel and **(b)** counter flow schemes for one layer open-cell SiC volumetric solar receiver with different combinations of porosities and cell sizes.

4. **CONCLUSIONS**

- The counter-flow scheme exhibited higher thermal performance than the parallel-flow scheme at the same porosity and cell size values of the porous ceramic foam.
- For the parallel-flow scheme, the lower porosity and the higher cell size porous ceramic foam configuration exhibited higher thermal performance. In contrast, the lower porosity and the lower cell size porous ceramic foam configuration exhibited higher thermal performance for the counter-flow scheme.
- Additional future work may include a double-layered SiC volumetric solar receiver structure with different combinations of cell sizes and porosities within parallel and counterflow schemes to maximize the outlet air temperature at the lower pumping power needed.

ACKNOWLEDGMENTS

The authors express their profound gratitude to King Abdullah City for Atomic and Renewable Energy (K.A.CARE) for their financial support in accomplishing this work.

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