Abstract

Development of high-performance receivers equipped with a metal porous matrix

This dissertation focuses on enhancing solar receivers for Concentrated Solar Power (CSP) facilities to promote their efficiency and increase their contribution to sustainable development. By integrating metallic Raschig Rings (RR) porous media, the aim is to boost heat transfer within the absorbers, thus improving power generation. The enhanced solar absorbers play a dual role in climate change actions, following both mitigation and adaptation approaches.

The project spans various research lines, covering both point-focusing and linear-focusing systems, to ensure comprehensive integration and optimization of RR porous media in CSP applications. In the first phase, some preliminary investigations were performed to address the potential of the proposed technology in each specific application field and devise a sample for further experimental investigations. Although the two applied systems showed considerable efficiency improvements from the RR porous integration, point-focusing system was addressed more in detail through an experimental campaign.

During the experimental stage, several samples designed from the previous phase were manufactured and installed in a real-scale solar furnace in Spain. Furthermore, the efficacy of the two enhanced receivers was analyzed and interpreted from both energetic and exergetic viewpoints. In the next step, numerical investigations were employed to develop robust models for simulating RR porous media at different levels. Firstly, in micro-scale studies, a CFD-based numerical model was developed, verified, and rigorously validated against experimental data. The achieved model examined and optimized various numerical parameters such as RR randomness, porous effective thermal conductivity, and fluid turbulence models during the validation process. In parallel, equivalent macro models operating based on effective properties were developed to mitigate long computational times while still ensuring reliable results. This model is based on 3D microscale simulations and was validated by comparing results at both macro and micro levels, simulating applications in Linear Fresnel Reflector solar systems. At the final stage, further advancement and optimization measures were employed in each design category to promote the efficiency, cost-effectiveness, and sustainability of the enhanced receivers. In this regard, for the case of linear-focusing solar systems, the integration of intermittent RR packed beds with an air-based solar receiver demonstrated that intermittent porous blocks enhance heat transfer, particularly at high Reynolds numbers, by increasing turbulent conditions between beds. Furthermore, in the case of point-focusing systems, two innovative partial filling porous concepts, one entailing lateral filling and the other central filling, were explored and compared employing CFD models. Detailed analyses of fluidic and thermal characteristics were conducted to ascertain the most optimal configuration. Additionally, comparing the proposed advanced porous inserts

with existing models in the literature highlights the potential advantages of RR in improving the overall efficiency of tubular solar absorbers.

The final conclusions showed that although various applications of RR porous inserts could improve the thermal efficiency of current CSP systems through experimental and numerical investigations, partial filling is one of the most effective techniques in minimizing the increase in pressure drop associated with full porous insertion, reducing it by up to 95%. Assessing the overall performance of the absorbers, considering the instantaneous effects of pressure drop and thermal enhancement, revealed that the partially filled design could effectively enhance the performance of a simple tube design, providing 40% and almost 90% higher energy and exergy efficiencies, respectively. More findings and outcomes are presented in chapter 6, offering robust reasoning regarding various designs and their achievements at each stage. Ultimately, it provides a comprehensive overview of the lessons learned, outlining future application opportunities, and barriers to further advancement in the solar energy sector.