

Summary

Concentrated solar power (CSP) technology has captured significant attention over recent decades due to its capability to provide large-scale, renewable energy with the advantage of thermal energy storage, which allows for a dispatchable power production. In this context, this dissertation investigates computationally various features of CSP systems, aiming at introducing specific strategies for the enhancement of overall efficiency and sustainability. This investigation is conducted through three main activities: the optimization of the photo-thermal performance of a parabolic trough system, the comparative techno-economic assessment of various linear CSP technologies, and the thermal performance enhancement of a case study thermocline thermal energy storage system.

The first objective of this dissertation is to propose a new strategy to optimize the photo-thermal performance of a parabolic trough system, through arranging multiple selective coatings along the collector line. This optimization is based on a lumped-parameter model in the radial direction and a 1D model in the axial direction of the receiver tube, which was newly developed for that purpose. Consequently, the most photo-thermally efficient configuration of the receiver tube is presented, characterized by three different selective coating formulations implemented at the three different temperature ranges expected along the receiver. This optimized configuration improves the overall photo-thermal efficiency of the system, in comparison with the single-coated collectors. Moreover, this approach could reduce the receiver cost, owing to the employment of the more expensive selective coating only at the final collector segment.

The second goal of this dissertation involves conducting a comparative techno-economic feasibility assessment among various linear CSP technologies, encompassing evacuated and non-evacuated configurations of linear Fresnel and parabolic trough systems. This comparison is carried out in terms of levelized cost of electricity (LCOE), considering four different locations worldwide characterized by various levels of direct normal irradiation (DNI). The LCOE is determined by cost data and net annual energy yield of the CSP plant. While cost data is collected from existing literature, net annual energy yield is computed by a 1D axial model. This model is supported by an optical ray-tracing model and a radial lumped-parameter model. In addition, a 2D steady-state computational fluid dynamics

(CFD) model is developed in the case of the linear Fresnel receiver unit, where conventional correlations are not applicable for the convective heat transfer between the glass tube and the environment. Furthermore, a sensitivity analysis is performed to evaluate the effect of diverse techno-economic parameters on the LCOE.

Finally, this dissertation aims at enhancing thermal performance of a case study thermocline energy storage system. This improvement is achieved by geometric modifications and phase change material (PCM) integration through different scenarios. A transient 2D CFD model is developed to compute heat losses and temperature distribution within storage tanks. This model is coupled with a PCM lumped-parameter model to compute the PCM temperature and the corresponding heat transfer coefficient. By using these models, the thermal performance of various configurations is investigated for charge and discharge processes. Consequently, a comparative performance analysis is conducted between the proposed energy storage systems and the case study.