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Improving Next-Generation Falling Particle Receiver Designs Subject to Anticipated Operating Conditions

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Particles are a promising candidate for use in next generation concentrating solar power plants as the heat transfer medium. Unlike many competing alternatives, particles may be directly irradiated avoiding traditional flux limitations. Additionally, particles have been proven capable of reaching temperatures in excess of 700°C, leading to particle-based receivers with very high heating rates. However, careful consideration must be taken in the design of a solar particle receiver in order to minimize thermal losses. As part of the Generation 3 Particle Pilot Plant (G3P3) project, a next-generation 1 MW_{th} particle receiver is being designed with a targeted thermal efficiency approaching 90% utilizing the National Solar Thermal Test Facility (NSTTF) heliostat field.

Design of the particle receiver is adhering to the following strategy: (1) optimization of a candidate geometry under quiescent conditions, (2) investigation of candidate geometry performance subject to wind, and (3) investigation of maximum temperatures when irradiated with the NSTTF heliostat field. Two additional features are being investigated as further improvements to the design: (1) a ‘chimney’ to capture advective and particle losses from the aperture and (2) a multi-release concept. A thorough optimization routine has been performed to define a candidate geometry for the G3P3 particle receiver. This falling particle receiver (FPR) design releases a curtain of particles that falls past the beam of concentrated sunlight inside a north-facing cavity recessed into the tower through a converging tunnel. Coupled CFD models of the candidate receiver have demonstrated that a thermal efficiency of 87% can be achieved in quiescent conditions; however, further investigation is now required to ensure that the particle receiver can adequately sustain comparable thermal efficiencies at all operating conditions and enable steady-state operation when subjected to the maximum designed irradiance from the NSTTF heliostats.

In this study, CFD models of the candidate receiver are used to assess the thermal efficiency subject to various detrimental wind speeds and directions, and the sensitivity of the receiver thermal efficiency to the accompanying tunnel dimensions is quantified. Ray tracing models are coupled with CFD models to ascertain the maximum temperatures of the spillage board and receiver tunnel subject to the maximum irradiance provided by the NSTTF field. Additional numerical studies are also performed including other receiver features to further improve the design. Visualization of the entrained air in the cavity at temperature revealed that the presence of a ‘chimney’ near the exit of the receiver tunnel can be used to capture advective losses and escaping particle fines. Finally, the integration of a multi-release concept is evaluated to determine the concept’s effect on the thermal performance and the maximum receiver temperatures. In total, modifications made to the candidate receiver design from each of these studies demonstrates that the proposed G3P3 candidate receiver can deliver greater than 80% thermal efficiency in all operating conditions in steady-state operation.

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