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Optical design, optimization and economics of a solar polar-field tower system with an optional compound parabolic concentrator

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High-temperature receivers have been widely pursued for solar thermochemical applications or as part of broader strategies to increase system-level efficiency of solar power plants via increased power-cycle efficiency [1–5]. For high-temperature central receiver systems, compound parabolic concentrators (CPCs) are frequently proposed since they further increase the concentration ratio at the receiver aperture, and allow the mitigation of the high emission losses which occur at these elevated temperatures [6–9].

In this study, a system model is developed that incorporates an in-house Monte-Carlo ray tracing (MCRT) code for heliostat field and CPC modelling [7], a simple cavity receiver heat transfer model, and a cost model for the heliostat field, tower and receiver based on the SAM model [10] (Figure 1). For systems with a CPC, the field boundary is determined in two steps. First, heliostats with centres located outside the conic section created from the intersection of the CPC acceptance cone with the horizontal plane are removed. These heliostats have zero CPC efficiency due to backward reflection [11]. Second, the heliostat field is further trimmed by removing the heliostats with instantaneous field efficiency at autumn equinox noon lower than a trimming efficiency threshold (Figure 2).

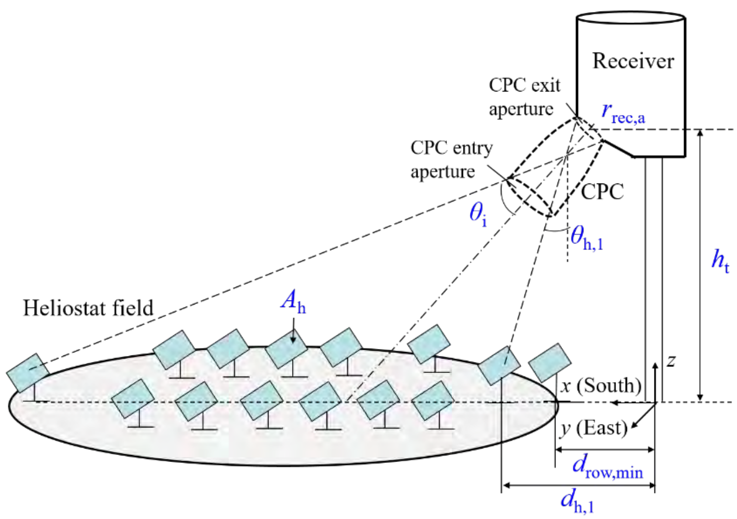

Figure 1. A model solar central receiver optical system with a heliostat field, a central tower, a receiver and an optional CPC.

We evaluate and compare the cost of the achieved concentrated radiation that can be used in various ways. Specifically, this study elucidates, for the typical application of concentrated radiation for power generation, how the optimal optical configuration varies with the receiver operating temperature, and at what temperatures a solar central receiver system may benefit from the use of a CPC with better optical or economic performance. Parametric studies on the effects of varying heliostat size, tower height, receiver aperture size, field layout, and CPC configuration are presented, showing how both the optical performance and the levelised cost of exergy are affected by each parameter. We discuss the performance factors in detail, with a breakdown of field optical performance at the single-heliostat level.

Based on these parametric studies, optimal heliostat field and receiver configurations for both maximum annual solar-to-exergy efficiency and lowest levelized cost of exergy are presented.

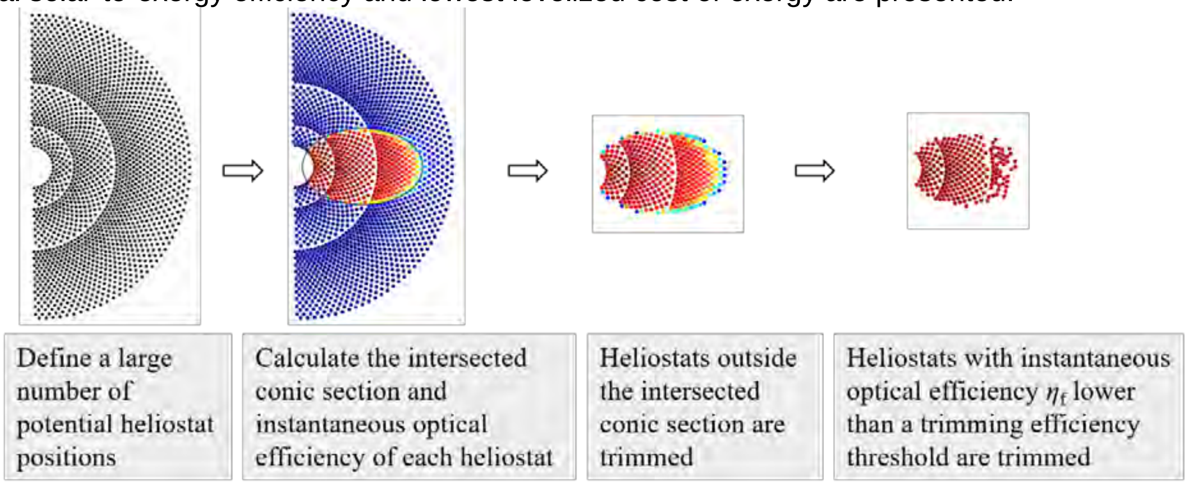

Figure 2. Determination of heliostat field boundary as implemented in this study [12].

References

[1] Ho, C. K. and Iverson, B. D., 2014, 'Review of high-temperature central receiver designs for concentrating solar power', Renew. Sust. Energ. Rev., 29, 835–846.

[2] Bader, R. and Lipiński, W., 2017, Solar thermal processing, in: Blanco M., Ramirez Santigosa L. (Eds.), Advances in Concentrating Solar Thermal Research and Technology. Woodhead Publishing, 403–447.

[3] Bayon, A., Bader, R., Jafarian, M., Fedunik-Hofman, L., Sun, Y., Hinkley, J., Miller, S., and Lipiński, W., 2018, 'Techno-economic assessment of solid–gas thermochemical energy storage systems for solar thermal power applications', *Energy*, 149, 473–484.

[4] Carrillo, A. J., González-Aguilar, J., Romero, M., and Coronado, J. M., 2019, 'Solar energy on demand: A review on high temperature thermochemical heat storage systems and materials', Chem. Rev., 119, 4777–4816.

[5] Li, L., Coventry, J., Bader, R., Pye, J., and Lipiński, W., 2016, 'Optics of solar central receiver systems: a review', Opt. Express, 24 (14), A985–A1007.

[6] Winston, R., Miñano, J. C., and Benítez, P., 2005, Nonimaging Optics (Elsevier).

[7] Li, L., Wang, B., Pottas, J., and Lipiński, W., 2019, 'Design of a compound parabolic concentrator for a multi-source high-flux solar simulator', Sol. Energy, 183, 805–811.

[8] Schmitz, M., Schwarzbözl, P., Buck, R., and Pitz-Paal, R., 2006, 'Assessment of the potential improvement due to multiple apertures in central receiver systems with secondary concentrators', Sol. Energy, 80(1), 111–120.

[9] Segal, A. and Epstein, M., 2003, 'Optimized working temperatures of a solar central receiver', Sol. Energy, 75, 503–510.

[10] System Advisor Model Version 2014.1.14 (SAM 2014.1.14). National Renewable Energy Laboratory. Golden, CO. Accessed March 31, 2019. https://sam.nrel.gov/content/downloads.

[11] Winston, R., Miñano, J. C., and Benítez, P., 2005. Nonimaging Optics (Elsevier).

[12] Pfahl, A., Coventry, J., Röger, M., Wolfertstetter, F., Vásquez-Arangoa, J. F., Gross, F., Arjomandi, M., Schwarzbözl, P., Geiger, M., and Liedke, P., 2017, 'Progress in heliostat development', Sol. Energy, 152, 3–37.