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Application of a Compound Parabolic Concentrator to a Multi-Source High-Flux Solar Simulator

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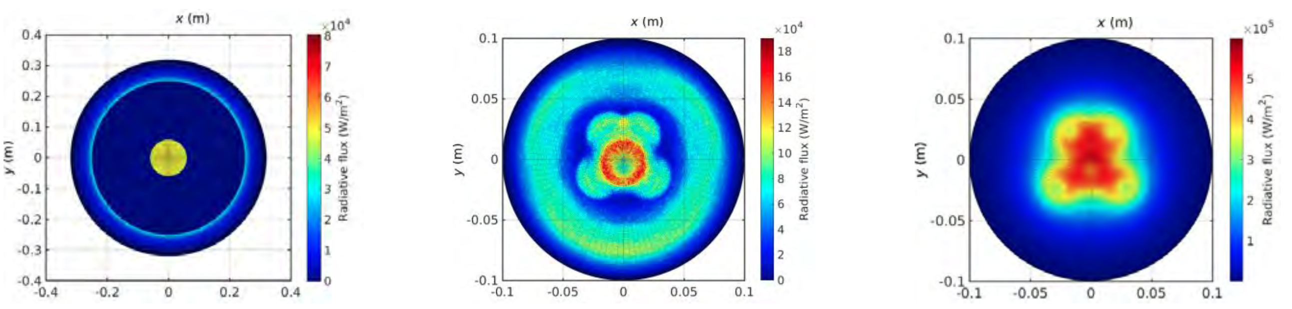
This study investigates optical characteristics of compound parabolic concentrators (CPCs) coupled to multi-source high-flux solar simulators (HFSSs) using Monte Carlo ray-tracing modelling. HFSSs are sources of artificial concentrated radiation for high-temperature solar thermal and thermochemical research. The HFSS facility at the Australian National University (ANU) is predicted to provide radiative peak flux in excess of 10 MW m^{-2} (Bader 2015). However, the high concentration ratio is accompanied by excessive radiative power. Besides, hot spots will appear inside the target cavity equal to the number of active lamps. The use of a CPC increases the concentration ratio ideally by a factor of $1/\sin\theta$ or $1/\sin^2\theta$ for a 2D or 3D CPC, respectively. A CPC allows for utilization of spillage radiation directly around the hot spot, and spreads the angular distribution of the exiting radiation. The latter, in turn, allows for more uniform radiation inside a receiver cavity, in particular for eliminating hot spots. The objective of this study is to investigate the application of CPCs for meeting the radiative power and concentration ratio requirements of a target reactor and improving the flux uniformity inside a target cavity.

Numerical simulations were performed using a Monte Carlo ray-tracing (MCRT) optical model implemented in an in-house developed Fortran program. First, simulations with uniform radiation from truncated spherical surface are performed. Emitted rays are perpendicular to the spherical surface. Figure 1a shows the radiative flux distribution on a hemispherical target of 0.3 m radius for a CPC of θ = 25°. Radiation is separated into two parts by the CPC. A portion of rays pass through the CPC without touching the surface and arrives in the central area of target hemisphere. The remaining rays are reflected by the CPC surface and redistributed on the outer area of target hemisphere.



(a) (b) (c)

Figure 1. Radiative flux distribution on a hemispherical target of (a) 0.3 m radius for a uniform radiation source and a CPC of θ = 25°; (b) 0.1 m radius for radiation from the bottom 5 HFSS lamps and a CPC of θ = 27°; and (c) 0.1 m radius for radiation from the bottom 5 HFSS lamps and no CPC.

An experimental solar thermochemical reactor based on a redox reaction with ferrite–manganese mixed metal oxides, used as a model reactor in this study, has a nominal design radiative power input of 2.5 kW and requires a concentration ratio of 3000 suns. The present study provides an optimised design, in which the bottom five lamps of the HFSS are used in tandem with a CPC of 27° acceptance angle and 0.035 m entry aperture radius. For comparison, radiation on the hemispherical target with and without CPC is shown in Figure 1b and Figure 1c, respectively. Additional lamps can be optionally turned on if higher power or concentration ratio are desired, in which case excessive spilled radiation on the CPC entry aperture plane needs to be removed.

Optical analysis of a CPC coupled with the ANU HFSS is conducted. The present study demonstrates that the redirection of radiation by a CPC improves the radiative flux uniformity in the target cavity. It enables matching power and concentration ratio requirements of high-temperature solar receiver–reactors. Radiation spillage, and consequently waste heat management requirement, are reduced. Greater flexibility in using different combinations of the solar simulator lamps is achieved. In a large-scale central receiver system, a CPC can be employed in a geometrically similar configuration to meet high radiative input requirements of high-temperature solar receiver–reactors.

References

Bader, R., Haussener, S. and Lipiński W, 2015, “Optical design of multisource high-flux solar simulators,” *ASME Journal of Solar Energy Engineering*, 137, 021012.