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Thermal Model of a Solar Thermochemical Reactor for Metal Oxide Reduction

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A transient heat transfer model is developed to study the thermal performance of a conceptual high-temperature solar reactor for metal oxide reduction. The solar rector features an indirectly irradiated tubular fluidized bed inside a cavity (Figure 1). A compound parabolic concentrator (CPC) is implemented by truncating the bottom corner of the cylindrical cavity to concentrate the incident radiation to approximate 3000 suns at the CPC outlet. The concentrated radiation heats the metal oxide particles in the tube-confined bubbling fluidized bed to the reduction temperature of 1800 K.

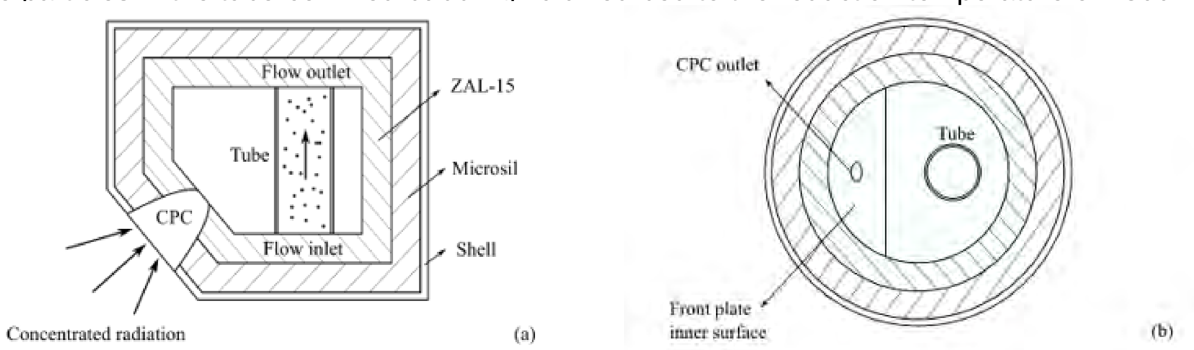

Figure 1. Schematic of the solar thermochemical reactor: (a) side and (b) top view (Wang 2018).

The reactor model couples the incident high-flux irradiation with radiative heat exchange in the cavity and conduction heat transfer in the reactor tube and cavity walls. The radiative heat transfer is modelled with the Monte Carlo ray-tracing method. The energy conservation equation is solved using the finite volume method and explicit Euler time integration scheme. The numerical model is implemented in Fortran. Non-conforming mesh is applied to irregular shapes. Adaptive time stepping is applied to reduce the computational cost of the transient solution.

The model is applied to study the reactor thermal performance, such as the maximum temperature and thermal stress in the reactor components, start-up time, energy balance, particle reduction rate and the influence of the incident radiation directionality, to enlighten the design and optimisation of the reactor. The calculated tube maximum temperature approximates the maximum allowable temperature. The maximum thermal stress of the tube is within the safe range. The solar-to-thermochemical energy efficiency is 46.3%–57.4%. Assuming the reactor is applied to fully reduce Mn_3O_4 to MnO, the according reduction rate of the Mn_3O_4 particles is 0.70–0.87 g s^{-1}. Directional distribution of the incident radiation is found to have an insignificant effect on the reactor thermal performance.

Reference

B. Wang, V. M. Wheeler, J. Pottas, P. B. Kreider and W. Lipiński, 'Thermal modelling of a solar thermochemical reactor for metal oxide reduction', *Proceedings of the IHTC-16 International Heat Transfer Conference*, Beijing China, 2018.