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Towards Industrial Solar Production of Zinc and Hydrogen

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A two-step water-splitting thermochemical cycle based on the Zn/ZnO redox reactions is proposed for producing solar hydrogen; the two steps are (1) the solar-driven endothermal dissociation of ZnO and (2) the non-solar exothermal hydrolysis of Zn. The second step of the cycle has been experimentally demonstrated using an aerosol-flow reactor for in situ formation and hydrolysis of Zn nanoparticles. For the first step, the proposed chemical reactor concept is based on a rotating cavity receiver lined with ZnO particles that are held by centrifugal force and directly exposed to concentrated solar radiation. The functionality of the engineering design was experimentally demonstrated with a 10 kW reactor prototype tested in PSI's high-flux solar simulator at temperatures above 2000 K and peak solar concentration ratios greater than 5000 suns. The longest run exceeded four hours of operation. The peak solar-to-chemical energy conversion efficiency was 3.1±0.3%. A transient heat transfer model was developed for analyzing the thermal performance of the 10 kW reactor prototype in the 1600-2136 K range and for scaling up the reactor technology. The solar-to-chemical conversion efficiency of the prototype reactor can be increased to 17% by optimizing its geometry of the outlet section, primarily due to a decrease of conduction losses. Scaling up the reactor to 100 kW and 1000 kW nominal solar power input has the potential of reaching maximum solar-to-chemical conversion efficiencies exceeding 50%. Employing solar produced hydrogen in a fuel cell engine reduces fuel-associated greenhouse gas emissions by 94% compared to gasoline. Cost estimates for solar hydrogen produced by the Zn/ZnO cycle range from 10-14 US$/kg H_2 in a fuel cell car tank. In comparison, costs of about 20 US$/kg H_2 are predicted for water electrolysis using electricity from concentrating solar thermal power plants.