Hydrogen production via solar thermochemical water splitting

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The production of hydrogen free of CO_2-emissions is one of the main goals as well as a major challenge of a future hydrogen economy. An alternative to fossil fuels is to use water as a carbon-free resource for hydrogen production. It can be decomposed into hydrogen and oxygen either by means of electrolysis or via thermal splitting. Electrolysis requires two energy conversion steps: first the conversion of thermal to electric and second the conversion of electric to chemical energy. That means the overall process efficiency is limited by the efficiencies of both energy conversion steps. By thermal splitting of water thermal energy is directly stored in chemical energy. Because of thermodynamic restrictions, sufficient yields in the direct thermal splitting of water can only be achieved at temperatures above 2500 K. Temperatures that high impose extraordinary demands on materials and reactor design. Thermochemical cycles on the other hand split water in several steps and enable hydrogen generation at much lower temperatures which are manageable by today’s technical equipment. They have the potential to run with higher efficiencies than electrolysis coupled with the conversion of thermal energy to electricity. Another major advantage of a thermochemical cycle is that hydrogen and oxygen are produced in separate steps, i.e. no separation of hydrogen and oxygen is needed. If the necessary process heat is provided by a concentrated solar energy, the whole process runs without fossil fuels and hence without any CO_2-emissions.

A two-step thermochemical cycle has been developed at DLR in Cologne which incorporates mixed iron oxides as redox-materials for the water splitting. During the first step of this cycle (the regeneration step) the metal oxide (MO) is reduced setting some of its lattice oxygen free according to reaction (1). In the next step (the water splitting) the reduced and activated material is oxidised by withdrawing oxygen from water and simultaneously hydrogen is released according to reaction (2).

(1) $MO_{oxidised} \rightarrow MO_{reduced} + O_2$
(2) $MO_{reduced} + H_2O \rightarrow MO_{oxidised} + H_2$

The developed process uses ceramic honeycomb substrates which are coated with a thin layer of the redox material. These coated substrates provide on the one hand the surface area for the chemical reaction and on the other hand serve as solar absorbers. Through concentrated solar energy process temperatures between 800 °C and 1200 °C are reached. The work at DLR incorporates the basic principles underlying the process, like thermodynamic and kinetic investigations, as well as the technical realisation of the reactor concept. For this purpose several reactors have been built and tested at the solar furnace of DLR in Cologne. In these tests quasi-continuous hydrogen production could be achieved. Based on this concept a pilot reactor with a solar power input of 100 kW_{th} was built and successfully tested in South Spain.