THERMOCHEMICAL SOLAR ENERGY STORAGE VIA REDOX OXIDES: DEVELOPMENT OF A CONTINUOUS ROTARY KILN REACTOR FOR REDOX REACTIONS WITH COBALT OXIDE

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Abstract

The extensive use of regenerative energies like solar power needs reliable long term storage system. One attractive system is the thermochemical storage process, which is enabled by reversible chemical reactions. Concentrated solar power (CSP) supplies a solar receiver to execute an endothermic chemical reaction; in case the reaction is completely reversible, the thermal energy can be entirely recovered. The exothermic reverse reaction occurs during off-sun operation, releasing the heat which can be used to supply a conventional power generation block, like the case of a usual on-sun operation of CSP power plant. Among possible totally reversible gas-solid chemical reactions, the utilization of a redox reaction like the cobalt oxide cycle, shown below, can be directly coupled to CSP power plants providing hot air as heat transfer fluid. In this case the air can be used both as heat transfer fluid (for example in solar tower systems applying volumetric air receivers) and as reactant, thus avoiding an additional heat exchanger.

$$2Co_3O_4 + \Delta H \leftrightarrow 6\ CoO + O_2 \qquad \text{(eq. 1)}$$

With $\Delta H = 202\ kJ/mol_{react}$

The present work deals with the development of a continuous working reactor for thermochemical storage systems based on cobalt oxide redox cycles. Subsequently, the reactor's thermal behaviour is modelled and afterwards validated through the experimental setup. While the detailed laboratory scale testing of material samples using a combination of thermo-gravimetric analysis/differential scanning calorimetry was executed within the EU-funded projects RESTRUCTURE and STOLARFOAM, the here presented scaled technical process is considered in a DLR internal project. Furthermore, a previous campaign with a batch-working rotary kiln was carried out, showing the feasibility and good chemical conversions [1].

The newly developed process consists of two separated main steps: the reduction step, executed in the direct irradiated rotary kiln (endothermic reaction) and the oxidation step, taking place in the so-called oxidation tank (off-sun and exothermic reaction). The rotary kiln works continuously to fill the oxidation tank with reduced cobalt oxide. The reduced material can be stored in this oxidation tank to be oxidized at any later time. The main parameters are the storage capacity of 10kWh and the requirement to release it over a period of 1h. Solar radiation is fed into the system via the DLR high flux solar simulator (HLS), located in Cologne, Germany. The HLS provides a peak radiative power output of around 15 KW.

Knowing the challenges from the previous projects, the new reactor could be laid out and constructed with a separation system for the reduced material, to prevent any uncontrolled back reduction by strictly excluding air and oxygen. Additionally, a detailed rotating measuring system was developed and implemented as well as a working system for continuous particle feeding and extraction has been built.

In addition to the construction, numerical analyses with commercial CFD software were carried out. One simulation was calculated to point out the gas flow and distribution inside the rotary kiln. This could help predicting particle transportation with the gas, as the powder particles are around 10 µm in diameter. Moreover the thermal behaviour of the reactor was predicted.

An upcoming test campaign will be executed in the HLS to show the reactors general functionality under high temperature of around 1000 °C. Those test results will be used to validate and improve all simulation models developed until now. The project's goal is to operate the reactor under hot conditions with cobalt oxide.

Literature:

[1] M. Neises, S. Tescari, L. de Oliveira, M. Roeb, C. Sattler, and B. Wong, "Solar-heated rotary kiln for thermochemical energy storage," *Solar Energy,* vol. 86, pp. 3040-3048, 2012.