Mechanical Engineering Doctoral Defense

Multi-day thermochemical energy storage

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Abstract

Energy storage technologies are essential to overcome the temporal variability in renewable energy. The primary aim of this thesis is to develop reactor solutions to analyze the potential of thermochemical energy storage (TCES) using non-stoichiometric metal oxides (MOx), for the multi-day energy storage application. A TCES system consists of a reduction reactor and an insulated MOx storage bin. The reduction reactor heats (to ~1100 °C) and partially reduces the MOx, thereby adding sensible and chemical energy (i.e., charging it) under reduced pO2 environments (~10 Pa). Inert gas removes the oxygen generated during reduction. The storage bin holds the hot and partially reduced MOx (typically particles) until it's used in an energy recovery device (i.e., discharge). Irrespective of the reactor heat source (here electrical), or the particle-inert gas flows (here countercurrent), the thermal reduction (TR) temperature and inert gas flow minimize when the process is reversible, i.e., operates near equilibrium. This study specifically focuses on developing a reduction reactor that is developed with the theoretical considerations for approaching reversibility along the reaction path. Along with the reactor development, the study identifies the key parameters that maximize the output energy storage density and reactor power density to enable TCES cost reduction. The proposed Zigzag flow reactor (ZFR) is capable of thermally reducing CAM28 particles at temperatures ~1000 °C under an O2 partial pressure ~ 10 Pa. The models developed in this study analyze the reaction equilibrium under a real (discrete) reaction path and the kinetic conditions necessary to approach equilibrium. Two functional ZFR prototypes, the Alpha-ZFR and the Beta-ZFR, establish the proof of concept and analyze the reactor scaling characteristics to estimate the levelized cost of thermochemical energy storage.

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