Solar Thermochemical Energy Storage Based on Iron–Manganese Oxide in a Packed Bed Reactor

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Concentrated solar power (CSP) incorporated with a thermal energy storage (TES) system has great potential to achieve the targeted objectives of clean electricity generation. Thermochemical energy storage (TCES) systems are less developed and presents higher technical complexity compared to more conventional TES sensible and latent heat storage systems. Although numerous metal oxide systems have been investigated for TCES redox processing to improve on conventional TES such as molten salt storage, none of these systems has fulfilled all the requirements of an ideal storage material (low cost, robustness, safety, and high energy density). For instance, pure manganese oxide is an inexpensive material that reacts at an acceptable temperature and has a moderate reaction enthalpy. However, its re-oxidation reaction is slow and its cyclability (robustness) is poor. On the other hand, iron oxide has a much higher reaction enthalpy and faster reaction kinetics, but suffers from a relatively high reduction temperature and deactivation upon sintering. Recent work has focused on a binary 1:3 Fe_2O_3:Mn_2O_3 system as a possible TCES system[1]. However, it seems likely that a higher Fe content will be desirable for faster kinetics and improved energy storage.

So, in this work, a binary mixture of 2:1 Fe_2O_3:Mn_2O_3 which forms iron manganese oxide spinel ($MnFe_2O_4$) on calcination is investigated as a potentially suitable TCES material. The XRD patterns in Figure 1 prove the presence of cubic spinel phase for the reduced state and show a bixbyite phase for the oxidized state of the material. The reduction reaction of this system has been studied using Thermogravimetric Analysis (TGA) in inert and air atmospheres. A shrinking-core model is considered for the reduction reaction of the particles. The results show the thermal reduction is controlled by oxygen internal diffusion for argon atmosphere. For the reduction reaction in air, the oxygen internal diffusion followed by oxygen external diffusion control the process. Figure 2 shows the modelling results versus the experimental data for the reduction reaction in a) inert and b) air atmospheres.

Furthermore, a lab-scale packed bed reactor has been designed and fabricated to analyze the thermochemical energy storage of iron-manganese oxide particles under infrared radiation. Several thermocouples are imbedded in the setup to get the temperatures at different locations of the packed bed reactor. The reaction conversion is calculated based on the generated oxygen which is measured by a mass spectrometer. Figure 3 shows the experimental setup. First, a 2D transient energy model has been developed to estimate the effective heat transfer parameters in the reactor packed with the active particles. Then, the results from the heat transfer study coupled with the reaction kinetics are used to predict the behavior of iron-manganese oxide particles in the packed bed reactor.

Reference

[1] Wokon, M et al., Solar Energy, 153, 471 (2017)

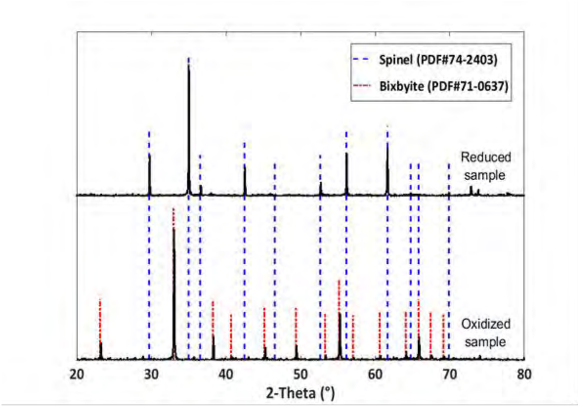

Figure 1: X-ray diffraction pattern of the iron–manganese oxide in the oxidized and reduced samples

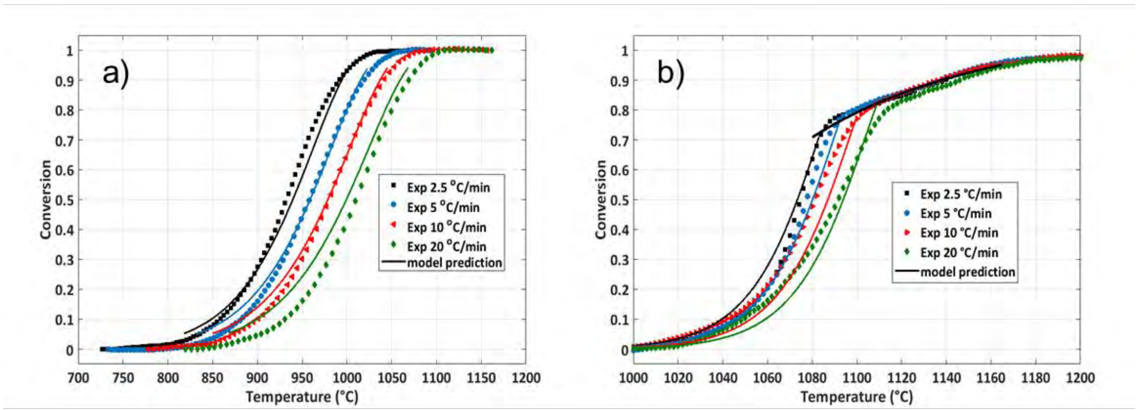

Figure 2: modelling result for the reduction reaction in a) inert and b) air atmosphere

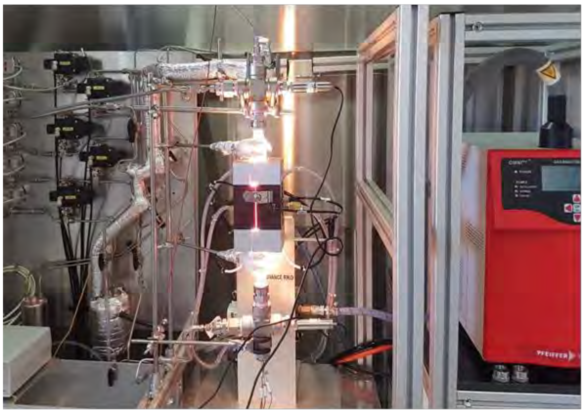

Figure 3: lab-scale packed bed reactor for thermochemical energy storage