Development of a Packed Bed thermal Energy Storage Prototype with Sodium as the Heat Transfer Fluid

Joe Coventry[1], Juan F. Torres[1], Zebedee Kee[1], Mehdi Vahabzadeh Bozorg, Mahdiar Taheri[1], Ahmad Mojiri[1], John Pye[1], Stuart Bell[2], Geoffrey Will[2] and Ted Steinberg[2]

[1] School of Engineering, Australian National University, Canberra, Australia.

[2] School of Mechanical, Medical and Process Engineering, Queensland University of Technology, Brisbane, Australia

* Corresponding author: joe.coventry@anu.edu.au

1. Introduction

The choice of an appropriate thermal storage technology depends on many application-specific factors, a key one being the temperature range over which heat needs to be supplied. Sodium is an attractive heat transfer fluid for high temperature applications, but as a storage medium has certain drawbacks: only moderate specific heat capacity, and cost higher than alternative bulk storage materials. Also, as a flammable material, minimising inventory is preferable. Therefore, it is better to use sodium in concert with other, different, storage materials. Here a concept is proposed where the sodium is in direct contact with a solid material in what is known as a packed bed thermocline. Packed bed thermocline storage systems are most frequently studied in a configuration with natural rock beds and air. Direct contact between sodium and solid materials has been proposed previously [1], but the challenge of identifying and testing a suitable storage material compatible with sodium has not yet been addressed. In this work, low-cost commercial grade magnesia is proposed, and the results of initial compatibility testing are presented. Another feature of this concept is tight packing of the filler material. Tightly packed bed storage concepts have been tested in air–ceramic storage systems, eg. [2]. Here it is proposed that the storage material is formed into rectangular cuboids (or *bricks*) packed tightly together to minimise the tank size and sodium inventory. The brick layout forms a self-supporting structure with narrow channels that provide a flow path and heat-exchanging surfaces. In this way, it is expected that the total inventory of sodium can be kept below 5% by volume. Importantly, the self-supporting structure eliminates ratcheting issues experienced in conventional packed beds.

2. Choice of material

Magnesia (MgO) was down-selected for experimental investigation over several other filler materials of interest (Al_2O_3, pig iron) as, based on modelling using the FactSage software, it was predicted to have good thermodynamic stability in contact with sodium at 750°C. Samples of ~97% purity commercial-grade magnesia bricks were sourced from several different bulk manufacturers. Samples were cut from the bricks and immersed in sodium at 750°C for an 18-hour period. Although a colour change was observed, x-ray diffraction (XRD) analysis indicated that the main crystalline phase (MgO) was unchanged (Fig. 1).

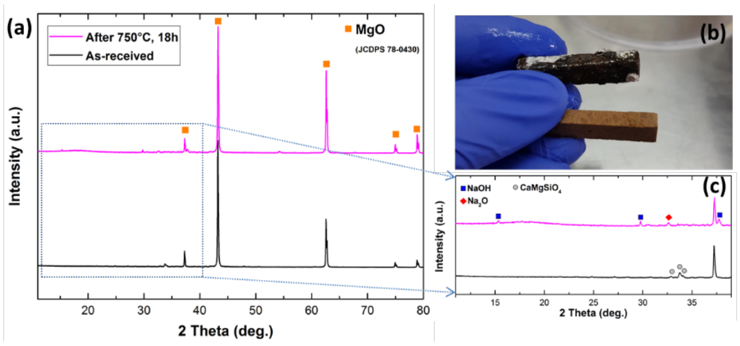

Figure 1. (a) XRD patterns and (b) appearance of the MgO sample from one supplier before and after immersion at 750°C, (c) enlarged XRD patterns.

3. Performance modelling

Computational fluid dynamics (CFD) modelling of the charging, discharging, and hold processes has been carried out, and the effect of brick size and orientation on pressure drop has been investigated. Narrow channels can increase the pressure drop, but it was found that, due to a reduction in the interface surface area, the pressure drop through the brick bed was significantly lower than for a packed bed filled with sand and small pebbles. Annual system modelling in SolarTherm was used to compare single-tank and multi-tank configurations. A reduced-order ‘surrogate’ model for the storage was developed to simplify and streamline optimisation based on annual simulations, relying on the assumption that operation of storage is *mostly* a repetitive cycle of fully charging and discharging. The system optimisation based on a single tank yielded levelised cost of energy (LCOE) of 56.55 USD/MWhe, an improvement compared to LCOE of 59.73 USD/MWhe for a reference case used as the cost baseline, which was a sodium / two-tank chloride salt / sCO_2 Brayton power cycle, similar to Turchi et al. [3]. The savings largely arise from the elimination of an entire tank, compared to the two-tank concept. Further reduction of LCOE is expected, once simulations of multi-tank packed-bed storage configurations are completed.

4. Prototype testing

A bench-scale prototype has been fabricated, in preparation for testing in the ANU sodium laboratory. The prototype (Fig. 2) has a volume of 45 L and incorporates 35 MgO bricks and half-bricks (full size 76 × 76 × 230 mm), placed inside a 316 stainless steel shell, with a 4 mm gap between the bricks in the horizontal and vertical directions. The system is designed to supply heat over the range 520–740°C.

(a) (b) (c)

Figure 2. Packed bed storage prototype showing (a) the fully assembled prototype (b) the bricks prior to the door being welded in place and (c) a sectional CAD view showing how the bricks are stacked.

5. Conclusions

Key benefits of this concept are that: (1) low-cost MgO filler is already produced at commercial quantities; (2) the total tank volume is smaller compared to conventional two-tank molten salt storage; (3) a second heat exchanger can be eliminated, if comparing to a sodium–salt system, which simplifies design, operation, and maintenance; and (4) the packed bed arrangement allows a low sodium inventory in the tank, reducing costs and hazards associated with storing large amounts of sodium. The next step for this concept is testing at ANU in its high-temperature sodium laboratory.

5. References

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