Exploration of Li_2SO_4 for High Temperature Thermal Energy Storage

ASTRI P21 – High Temperature Thermal Energy Storage

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Lithium sulphate is evaluated as a thermal storage material to be coupled with Concentrated Solar Thermal (CST) power plants. The energy is stored in a cubic crystalline phase that is formed at temperatures above 570 °C and can potentially be discharged at low temperatures down as low as 150 °C providing both sensible and latent thermal energy.

Introduction

Thermal Energy Storage (TES) is a key component of a solar thermal power plant providing energy dispatchabiliy to allow matching production and demand. Li_2SO_4 is a promising material that can provide thermal energy storage in both sensible and latent heat, as it undergoes a solid-sold phase transition at 576 °C. The fact that the material remains in provides several advantages in terms of corrosion and volume expansion. Lithium sulfate undergoes a volume change of only 3% which is very attractive from an engineering perspective as it greatly simplifies the mechanical issues of containment [1]. Lithium sulfate also has a high energy storage density compared with many of the currently investigated PCM materials. Furthermore, combining sensible and latent heat is highly beneficial for this system as the lower storage temperatures possible to achieve with this material can highly reduce the overall cost of the storage system.

Although several investigations has been conducted with lithium sulphate, its long term stability remains unexplored. In addition, a techno-economic evaluation has not been considered for the use of both sensible and latent heat. In this work, the material is evaluated in long term stability experiments and techno-economic assessment is provided.

Experimental Procedure

Figure 1: SETSYS Evolution 1750 used to evaluate the Li_2SO_4 performance

Commercial Li_2SO_4 (Sigma Aldrich 98.5%) was tested in repeated cycling experiments. The thermal behaviour was analysed under N_2 (99.99%). The cycling performance was evaluated in a TGA-DSC analyzer (SETSYS Evolution 1750) using 25mg±1mg of sample for each experiment.

Cost data calculation

TES system cost was used to evaluate the potential of lithium sulphate as a TES material. The cost analysis was performed considering the upper and lower temperature limit of the material obtaining a tank storage design based on the Figure 2 [2]. The cost data of materials and the labour cost was added to obtain the final storage cost of the device. The cost of lithium sulphate was estimated at USD 6 per kg, while the cost of the reference Salt Stream 700 (SS700) was estimated at USD 1.45 per kg (both obtained from literature).

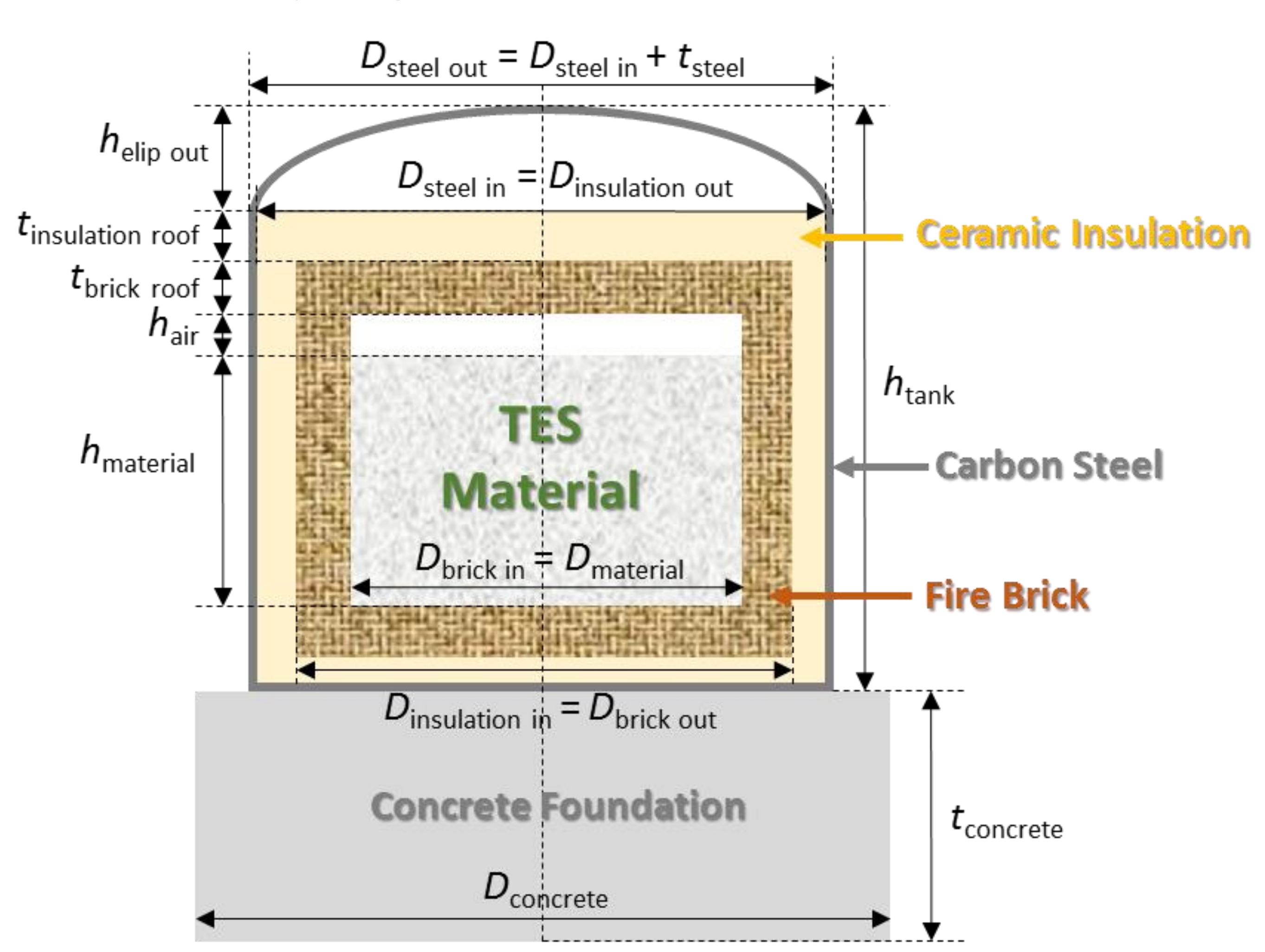

Figure 2: Design of storage tanks used for the cost comparison of lithium sulphate with Salt Stream 700.

Long term stability

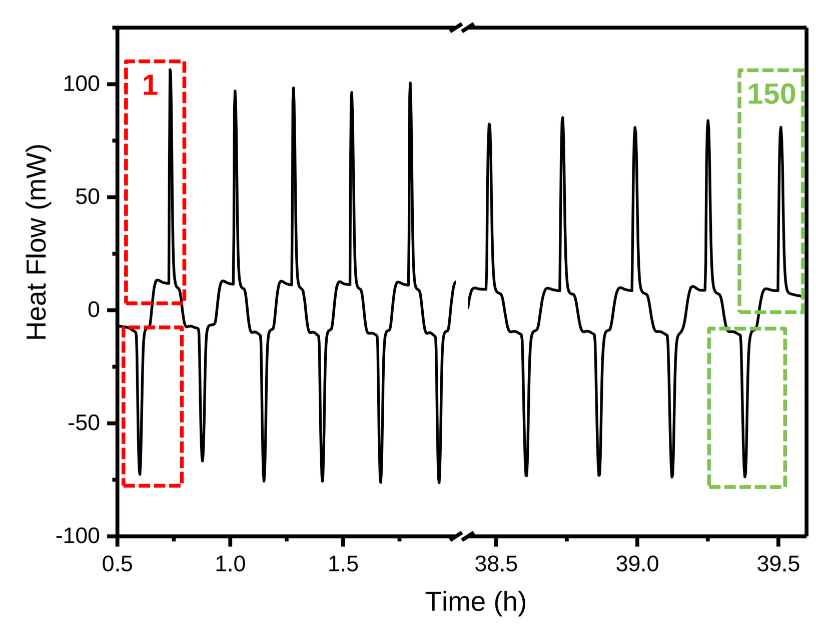

Figure 3: 150 cycles of Li_2SO_4 under N_2 atmosphere

The variation of the latent heat before and after the long term thermal treatment is shown in Figure 3. The capacity reduction is 4% compared with the theoretical value. In terms of latent heat, the values varied from 243.73 in the first cycle to 237.15 kJ/kg in the 150th cycle. These values are slightly less than the theoretical latent heat of 248 kJ/kg. However, cycling performance is excellent even after 150 cycles.

Cost comparison

Lithium salts are the main raw material used in electrochemical energy storage devices such as Lithium-ion or Lithium-sulfur batteries. Li-ion batteries cost of the order of USD 500-1500/kWh_e, with an energy density of 250–620 kWh_e/m^3 and limited performance life with less than 3000 charge and discharge cycles [3]. By contrast, Li-Sulphur batteries are well known for their high energy density of 350 kWh_e/m^3 and moderate cost of about USD 300-1000/kWh_e.

However, if lithium is used as a thermal battery, the storage density is about half compared to lithium based batteries. Despite this disadvantage, the cost of Li_2SO_4 TES is significantly lower and can provide a cheap energy storage consisting of USD 49/kWh_e overall. However, the capacity of the storage system is dependent on the temperature range. If only the latent heat is considered, the total cost of storage is USD 242/kWh_e. This is due to the lower capacity of the material only latent heat is considered (63.65 kWh_e/m^3). Therefore, when the sensible heat is taken into account, the cost reduces to a quarter of the initial value (between 150 and 700 °C). The cost of lithium sulphate TES is also 30% lower than SS700.

Table 1: Storage capacities and cost of lithium-ion battery, Saltstream 700 and lithium sulphate TES.

	Sensible Heat (kWh_e/m^3)	Latent Heat (kWh_e/m^3)	Total capacity (kWh_e/m^3)	Cost of material (USD/kWh_e)	Cost of storage device (USD/kWh_e)	Total cost (USD/kWh_e)
Li-ion battery*	NA	NA	620	4	400	404
Salt Stream 700 (300-700 °C)	78	-	78	39	38	71
Li_2SO_4 TES (only latent)	-	64	64	207	35	242
Li_2SO_4 TES (150-700 °C)	268	64	332	40	9	49

Conclusions

Cyclic experiments have shown that lithium sulphate exhibits good long term stability for use in TES systems. Very small differences in the sensible and latent heat from the powders were observed. In addition, a preliminary techno-economic evaluation has been conducted against molten salts and Li-ion batteries. Results shows that the large heat capacity of lithium sulphate suggests it could be competitive with commercially available systems. However, larger exploration of the material is required to assure its commercialization. Corrosion testing and moisture stability are two of the main factors that needs to be addressed in the future. Implementation in a practical system will also need to address issues around heat transfer in a solid system.

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