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Review of technology: Thermochemical energy storage for concentrated solar power plants

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ABSTRACT

To be able to extend the operation of a solar power plant (CSP) up to 15 h, thermal energy storage (TES) is necessary. But TES also provides more versatility to the plant and makes its reliance during operation hours more dependable. On the other hand, due to the different CSP configurations, a broad spectrum of storage technologies, materials and methods is needed. Sensible and latent heat storage are known technologies in CSP, but thermochemical storage (TCS) is still very much at laboratory level. Nevertheless, TCS has de advantage of nearly no losses during storage and very good volumetric energy density. This review summarizes and compares the different TCS that are today being investigated. Those systems are based in three redox reactions, sulfur-based cycles, metal oxide reduction–oxidation cycles, and perovskite-type hydrogen production, and metal oxide non-redox cycles due to their similarity. This review shows that all these cycles are promising, but none of them seems to have all the characteristics necessary to become the only one storage system for CSP. The main conclusion of the review is that the calcium carbonate is the cycle with most experimentation behind it to infer that it could be viable and should thus be attempted at a research plant scale once a reactivation cycle can be designed; and the manganese oxide cycle, while less developed, is fundamental enough to be a suitable application for desert climates over the rest of the water-frugal or even water-avoiding cycles.

Contents

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1. Introduction

The added hours of operation and competitiveness needed boosted solar power installations to incorporate thermal storage units, which became ubiquitous in any new concentration solar plant project. The need to extend the operation of the plant by two, four, or even 15 h (such as in the Gemasolar installation near Granada, Spain; or Cerro Dominador installation to be built in Chile) not only makes the plant more versatile to comply with unexpected demand peaks during night time, where no power is being produced, it also makes its reliance during operating hours much more dependable: stored energy can keep output steady during transition periods such as a cloud pass or dangerous winds [1].

There are two more known types of TES system, sensible storage system and latent storage system. These systems are based on the increment of temperatures in the material by the effect of the energy transfer in the case of sensible system; or based on the heat of fusion or vaporization during the phase change of the storage medium (solid to liquid or liquid to gas). The third thermal energy system is based on the use of the heat reaction in a reversible chemical reaction [2].

In contemporary industrial practices, thermal storage units have been greatly limited to sensible heat technology: using high thermal capacity materials like sand, molten nitrate salts, or saturated steam, to retain heat for differing amounts of time depending on the material. Steam accumulators, which store saturated steam at high pressures of 50 bar (such as in the PS10 tower in Sanlúcar la Mayor, Spain), can provide 20 min of extra power at full capacity [3]. Salt towers, having a much higher specific heat capacity, can retain heat for a longer period and dispense it efficiently. In Gemasolar or Cerro Dominador, as mentioned before, this means that they can theoretically operate uninterrupted by using solar power during the day and the stored surplus energy, kept in the molten salts, through the night. Due to diversified demand profiles (with respect to type, amount, and power of needed energy), each energy storage (electrical, thermal, mechanical or chemical storage) requires a specific, optimal solution regarding efficiency and economics.

For thermal energy storage systems it can be derived that there is more than one storage technology needed to meet different applications. Consequently, a broad spectrum of storage technologies, materials and methods is needed. The overall target in designing TES systems is the reduction of investment cost, the