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A proposition of peritectic structures as candidates for thermal energy storage

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Abstract

Peritectic structures are proposed as candidates for thermal energy storage in solar power plants. According to the evolution of Concentrated Solar Plants (CSP) technologies, the development of a new technology for ultra-compact Thermal Energy Storage (TES) over an extended range of temperatures is required. Identification, synthesis, analysis and characterization of innovative advanced materials should allow reaching outstanding energy density, long term stability, reasonable investment and could also enhancing heat transfers. All these assets make the 'peritectics' very appealing potential candidates for heat storage. In this work, a theoretical study based on phase diagrams modeling is performed to investigate the possible use of binary peritectic structures. It has been shown that peritectics can provide significantly increased energy density compared to simple melting/solidification processes, mainly because they involve chemical reactions. These materials could hence represent a very innovative and promising route for ultra-compact heat storage over a wide range of temperatures [300 - 700°C].

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Keywords: Peritectic structures, thermal energy storage

1. Introduction

Thermochemical Heat Storage (THS) is intensively studied because it is a nearly lossless way of storing energy when the chemical reaction materials are stored separately and because it could provide high values of volumetric energy density. Currently, THS can provide the highest heat storage followed by Latent Heat Storage (LHS) and then, by Sensible Heat Storage for the same amount of material [1]. Various kinds of gas-solid reaction systems are

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under investigation: dehydrogenation of metal hydrides (80-400°C), dehydration of metal hydroxides (250-800°C), decarboxylation of metal carbonates (100-950°C), and thermal desoxigenation of metal oxides (600-1000°C) [2]. The enthalpy of reaction is usually extremely high, 400-1100 kWh/m^3 depending on the temperature, which makes THS a very promising alternative. However, their feasible volumetric energy density is between 200 and 500 kWh/m^3 only, because of several requirements such as the full interaction needed between the reactant materials or the impact of internal and external conditions of the thermochemical systems on the productivity rate, for instance [1]. THS development is, thus, still in a fundamental, laboratory stage and far from any proven design and material to be transferred to a relevant scale.

This work aims at participating to the development of a new kind of materials which are able to combine the melting/solidification processes with chemical reactions. Contrary to gas-solid reactions in which chemical reactants have to be separated, the liquid and the solid phases involved in peritectic formation separate and recombine by themselves. Moreover, the peritectic structures work at atmospheric pressure both in charge and in discharge. As a result, simple storage concepts, like one-single tank with storage material in bulk and embedded heat exchanger, could be applied.

Nomenclature

ROMAN LETTERS

T_p	Peritectic temperature
$\Delta T_{L\to p}$	Temperature between the liquidus and the solidus points
E_P	Energy density related to the peritectic reaction
$E_{L\to P}$	Energy density related to the gap between the liquidus and the solidus points
ΔH	Enthalpy change related to the peritectic reaction
$\Delta H_{L\to P}$	Enthalpy change added between the liquidus and the solidus points

ACRONYMS

CSP	Concentrated Solar Plant
LHS	Latent Heat Storage
PCM	Phase Change Material
TCS	Thermo-Chemical Storage
THS	Thermochemical Heat Storage

1.1. Concept and explanation

The proposal is based on a ground-breaking idea consisting in using chemical compounds formed during the peritectic transition, in which thermal energy is stored by two consecutive processes: a melting/solidification process and a liquid-solid chemical reaction. Thus, the so-called 'peritectics' present the major asset of combining sensible heat, latent heat and reversible chemical reaction.

Peritectic structures are formed by a reversible chemical reaction in which a liquid phase (L) reacts with a primary solid (α) on cooling to produce a new solid phase (β). Three classes of peritectic phase diagram have been identified based on the shape of the peritectic (β) solid-solution region [3] as shown in Fig. 1.

- Type A system where the $\beta/\alpha + \beta$ solvus and the β-solidus have slopes of the same sign. The phase β formed during the peritectic reaction is a solid solution of one of the system components
- Type B system where the slopes have opposite signs. As in Type A, the phase β formed is a solid solution of one of the system components
- Type C system where the β-phase has a limited composition, referred as stoiechiometric peritectic compound.