



# A novelty for thermal energy storage utilizing the principle of solid to solid phase change in a lithium sulfate at elevated temperatures

Amer Khalil Ababneh\*, Amjad S. Hijazin, Ali M. Jawarneh

Hashemite University, Zarqa, Jordan

## ARTICLE INFO

### Keywords:

High temperature thermal storage  
Solid-to-solid energy storage  
Storage for solar energy

## ABSTRACT

The novelty presented in this research includes a demonstration of storing thermal energy in a solid material  $\text{Li}_2\text{SO}_4$  by exploiting a fundamental principle of phase to phase change while remaining in solid form at elevated temperatures, above  $500^\circ\text{C}$ , using suitable heat transfer fluid; specifically, sodium-potassium eutectic alloy NaK. Analysis revealed that during the process of energy storage the solid storage material essentially remained within a narrow range of temperature which was best described as a temperature step wave traveling in the storage medium at near constant speed. The analysis also revealed the ease in scalability of the proposed constructional model to meet both rate of heat generation and storage capacity for various applications; i.e., in the area of solar energy. Specifically, it is shown that the rate of energy storage remains basically constant and that the duration of the thermal energy storage is linearly related to the length of storage material for the parameters considered herein. Also, since the temperature of the storage medium remains within a small range while storing thermal energy the implication is that the internal entropy generation is accordingly minimal. Additionally, for the storage material to be in the solid form it further renders the storage systems ease of handling and operation.

## 1. Introduction

Oftentimes in renewable energy systems and more so in solar system applications that one is confronted with the situation where much excess of energy is available at times when it is not needed; therefore, energy storage systems are implemented. Different forms of storage systems were devised to fulfill the various requirements for the many real life applications; e.g., batteries for electrical energy, solid iron for sensible heat, etc, as well described by many authors (Gil et al., 2010). However, often it is of interest to store solar thermal energy for later use. Thermal Energy might be put away in three distinctive alternatives: (1) based on storage material's sensible heat capacity where material temperature goes up; (2) by utilizing material's latent heat property that happens by phase change; or (3) via chemical potential, Gil et al. (2010). Chemical and phase change material (PCM) storage systems give chances for proficient systems; however, when querying about existing Thermal Energy Storage Systems (TESS) for concentrating solar power (CSP) plants it was found that they mainly store

in the form of sensible heat (Gil et al., 2010). For example, molten salt (solar salt™; which is an eutectic mixture of sodium nitrate 60% and potassium nitrate 40% where percentages are by weight) is liquid at ambient pressure in the range of temperatures  $220^\circ\text{C}$  and  $600^\circ\text{C}$  is utilized in steam power cycles. The disadvantage of using this medium is that the melting point is relatively high which means the pipes and valves have to be taken care of in terms of freeze blockage as well as its higher specific cost (Chemical Co., n.d.a). Major problems when using most of molten salt are phase segregation during cooling process which may be prevented by using a nucleation agent (Lane, 1983).

Blanco-Rodríguez et al. (2012) screened different metal compositions for utilization as PCMs for direct storage in plants. They settled on the eutectic magnesium-zinc alloy with magnesium 49% and zinc 51% by mass (MgZn) as the most reasonable one via thermo-chemical process. During 20 solidifying cycles, they affirmed literature values between  $340^\circ\text{C}$  and  $343^\circ\text{C}$  for the melting temperature and measured the enthalpy of fusion; however, they did not obtain any meaningful results regarding devising energy storage system.

**Abbreviations:** CSP, concentrating solar power; TESS, thermal energy storage system; HTF, heat transfer fluid;  $\text{Li}_2\text{SO}_4$ , lithium sulfate salt; NaK, sodium-potassium eutectic metallic alloy;  $\text{NaNO}_3$ , sodium nitrate salt; NPG, neopentyl glycol,  $\text{C}_5\text{H}_{12}\text{O}_2$ ; PCM, phase change material; PE, pentaerythritol,  $\text{C}_5\text{H}_{12}\text{O}_4$ ; TAM, trihydroxy methylaminomethane,  $\text{C}_4\text{H}_{11}\text{O}_3\text{N}$ ;  $A_c^{PCM}$ , cross sectional area of PCM;  $A_t^c$ , cross sectional area of tube;  $A_{inner}^t$ , inner surface area of tube;  $C_p^{HTF}$ , specific heat at constant pressure for HTF;  $C_v^{HTF}$ , specific heat at constant volume for HTF;  $C_i^{PCM}$ , specific heat of PCM at the ith node;  $C^t$ , specific heat of tube;  $k^t$ , thermal conductivity of tube;  $k_i^{PCM}$ , thermal conductivity of PCM at the ith node;  $\dot{m}_t$ , mass flow rate of HTF through the ith node;  $m_i^{HTF}$ , mass of heat transfer fluid in the ith node;  $m_i^{PCM}$ , mass of PCM in the ith node;  $m_i^t$ , mass of tube in the ith node;  $r$ , radial location;  $T_i^{HTF}$ , HTF's temperature at the ith node;  $T_i^{PCM}$ , PCM's temperature at the ith node;  $T_i^t$ , tube's temperature at the ith node

\* Corresponding author.

E-mail address: [ababneh\\_hu@hu.edu.jo](mailto:ababneh_hu@hu.edu.jo) (A.K. Ababneh).

<https://doi.org/10.1016/j.solener.2018.01.060>

Received 24 August 2017; Received in revised form 14 December 2017; Accepted 17 January 2018

0038-092X/© 2018 Elsevier Ltd. All rights reserved.

Chemical potential TESS store heat through a near reversible endothermic chemical reaction processes. As indicated by Tian and Zhao (2013), the three most imperative properties of the reaction in such a system are: chemical reversibility, extensive enthalpy change and basic reaction conditions. It is to be noted here that chemical reactions are inherently irreversible. Due to the very high energy densities of the reaction products, the methodology may pave the way to the generation of solar fuels, which is being re-investigated widely (Renewable Energy Carriers at the Swiss Federal Technical University (ETH) Zurich; Tian and Zhao, 2013). However, the innovation is still in a trial to pre-commercial stage, thus, it has not been evaluated in detail.

Storage of thermal energy with phase change materials is the most beneficial and proficient technique for putting away and storing the available energy as a result of several advantages; particularly, higher storage capacity per unit mass, isothermal operation and less storage space. Thermal energy storage system can gather energy as sensible heat or as heat of fusion, or a blend of both (Lane, 1983). Latent heat storage is more appealing than sensible heat storage in perspective of its high storage density with smaller temperature swing (Abhat, 1983).

Laing et al. (2010) demonstrated a combined sensible/latent heat TESS using concrete and  $\text{NaNO}_3$  as the thermal energy storage materials. The enthalpy of fusion of  $\text{NaNO}_3$  at  $306^\circ\text{C}$  is  $175\text{ kJ/kg}$ . This temperature is proper for direct storage in a superheated plant with charging and releasing pressures of 107 bar and 81 bar; respectively. A pilot program for TESS of this type was installed at an ordinary power plant which demonstrated when using finned tubes in a 700 kWh TESS they enhanced the releasing rate significantly (Laing et al., 2012).

Solid to solid phase change materials, for example polyalcohols, polyethylenes and layered perovskites are the most promising solid-solid PCMs. Among the polyalcohols, such as (neopentyl glycol,  $\text{C}_5\text{H}_{12}\text{O}_2$ ), (pentaerythritol,  $\text{C}_5\text{H}_{12}\text{O}_4$ ), (trihydroxy methyl-amino-methane,  $\text{C}_4\text{H}_{11}\text{O}_3\text{N}$ ) and so on are the focus of investigation (Benson and Chandra, 1985). At low temperature, these polyalcohols are heterogeneous, yet they wind up plainly homogeneous face-centered cubic crystals that have high symmetry and absorb a lot of energy for hydrogen re-bonding when their temperature goes up to the solid-solid phase change temperature. Experiments demonstrate that the polyalcohols experience a first-order phase transition during which the change in their Gibbs energy is zero (Wang, 1993). However, all for these are used for low temperature range.

Manipulation of storage material for the purpose of changing the temperature at which energy is stored also has been investigated. For example, Xiaowu Wang, Enrong Lu conducted an experimental study to investigate the heat storage performance of solid-solid phase change materials including the binary systems: NPG/PE and NPG/TAM; consisting of neopentyl glycol ( $\text{C}_5\text{H}_{12}\text{O}_2$ ), pentaerythritol ( $\text{C}_5\text{H}_{12}\text{O}_4$ ) and (trihydroxy methylaminomethane  $\text{C}_4\text{H}_{11}\text{O}_3\text{N}$ ). The experimental results of the heat storage performance of the binary systems of NPG/PE and NPG/TAM, under various molecule fractions, during heating and cooling processes that the second phase change stage ought to be primarily considered in the binary system NPG/PE or NPG/TAM with smaller NPG fractions whereas the first phase change peak ought to be primarily considered when the NPG fraction is large. At the point when the NPG fraction is large, it is smarter to utilize the second phase change enthalpy in applications which have a working temperature lower than  $40^\circ\text{C}$ , but for the smaller NPG fractions, the first phase

change enthalpy is too small, so it is recommended to utilize it in applications which have a working temperature higher than  $140^\circ\text{C}$  (Wanga et al., 1999).

Other solid to solid phase change materials, such as pentaerythritol ( $\text{C}_5\text{H}_{12}\text{O}_4$ ), pentaglycerine ( $\text{CH}_3\text{-C-(CH}_2\text{-OH)}_3$ ), neopentyl glycol ( $(\text{CH}_3)_2\text{-C-(CH}_2\text{OH)}_2$ ) and their mixtures, were used as potential candidates for space heating and process heat applications (Lane, 1983), since thermal energy at a temperature range between  $100^\circ\text{C}$  and  $400^\circ\text{C}$  is required for many industrial processes, e.g. in food, paper or chemical industry. For example the annual industrial heat demand in Germany is estimated to be 120 TWh in the fore mentioned temperature range. A large potential for energy saving is connected with this large demand; therefore, TESS should be incorporated into many of them (Lane, 1983).

The work presented herein deals with lithium sulfate  $\text{Li}_2\text{SO}_4$  as the solid medium for thermal energy storage utilizing NaK as the heat transfer fluid (HTF). To the best of the author's knowledge no one has been used or proposed the use of such combination for thermal storage purposes. Hence this methodology for storing energy was submitted for the office of patents whereby it is under the process of validation and approval (Ministry of industrial, trade and supply – Jordan; patent register number (2017/54)). The lithium sulfate exhibits the property where the crystalline structure changes from a certain orientation to another whereby this process requires heat and it occurs at a certain temperature level, see below. The choice for NaK is that it remains in the liquid form for a wide range of temperatures as well as its good thermal properties which lead to excellent value for heat transfer coefficient. Additional benefits for using lithium sulfate coupled with sodium potassium alloy are their availability and low cost (Pacio and Wetzel, 2013). Nonetheless, there are risks of chemical reaction of the NaK with air and water; however, these risks can be mitigated through the use of well containment methods in addition to the enforcement techniques of safety measures (Foust, 1972). It is to be noted although lithium sulfate may be in a particle form; however, in the context presented herein the form of the salt is to be in compressed form where this state may be achieved by initial compression the salt at high temperature below melting point so that it becomes intact and solid. This process is known as sintering. After achieving the solid form the compression would not be required any further and may be removed.

Specifically, the objectives are to demonstrate that the combination of  $\text{Li}_2\text{SO}_4$  and NaK can be adequately used in thermal energy transfer and storage systems. The adequacy of the storage material will include the scalability of the storage system to meet the required rate of heat of generation and the required capacity for applications that are usually found in intermittent solar systems. Therefore, a conceptual construction model was proposed, followed by identifying the governing equations based on the mass and energy conservation principles for assessing its thermal performance. The governing equations were thereafter discretized and solved numerically using well established numerical methods employing an in-house developed computer code.

### 1.1. Working fundamentals and rationale

It is known that when  $\text{Li}_2\text{SO}_4$  is brought up to about  $569^\circ\text{C}$  its crystal structure changes from monoclinic to face centered cubic (Rao and Prakash, 1975) as shown in Fig. 1, whereby this change in crystal

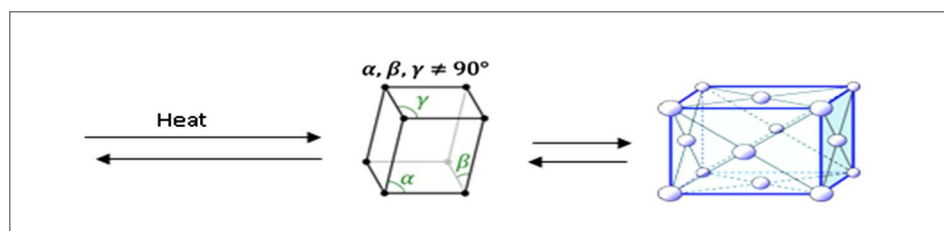


Fig. 1. Phase transformation from monoclinic to face centered cubic and vice versa with heat absorption/releasing at temperature approximately  $569^\circ\text{C}$ .

Download English Version:

<https://daneshyari.com/en/article/7935473>

Download Persian Version:

<https://daneshyari.com/article/7935473>

[Daneshyari.com](https://daneshyari.com)