An Estimate for Thermal Osmotic Heat Storage Using Precipitation of Common Salts

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In this brief note, a first assessment on the possibilities for thermal osmotic storage by harnessing the thermal dependence of the solubility of common salts as an alternative method to sensible heat storage is discussed. In a recent study it was found that such a dependence could be used to run a heat powered cycle (Osmotic Heat Engine). The question raised then, is whether that approach could be suitable for thermal energy storage as well. The attractiveness of such a possibility lies in the capability to store energy for an indefinite period of time without using expensive isolation systems if one considers that osmotic energy only is released when both streams with different salacities are brought together. Utilizing a simplified model, a comparative study with sensible heat storage was performed. It is shown that thermal osmotic storage via thermal precipitation of common salts could be an attractive option when long thermal storage (days) and compactness is desired.

Keywords. *Sensible heat storage, Osmotic energy.*

1. Introduction

The object of this note was a first scoping study to asses the attractiveness of harnessing the thermal dependence of the solubility featured for common salts for thermal osmotic storage in comparison with traditional sensible heat storage. Whereas salinity gradient based energy storage have been researched in the past in several aspects, [1], nevertheless, as far as the authors know, engineered osmosis has been proposed to store mostly electrical energy by separating brine and fresh water streams using modified reverse osmosis, and the only osmotic process driven by heat input is related with osmotic heat engines (OHEs) in which heat is applied to the OHE to re-concentrate the draw solution by vaporizing a portion of the water into steam, which would then be condensed to form the deionized working fluid, [2]. Another alternatives involved the chemical precipitation of solutes followed by their re-dissolution or removal of a volatile organic solute Loeb,[4]. More recent, [5], it was proposed that because the thermal dependence of the solubility of aqueous solutions, it could be possible to harness this feature to convert thermal energy into osmotic energy by separating a given solution into two different streams with different salinities using a process which is pictorially sketched in Fig. 1. Nevertheless, in that early work, the technique was intended to run powered heat cycles (osmotic heat engines), and the question of whether the method could be attractive for thermal storage in comparison with traditional approach (namely sensible heat) remained as an open question.

• Thermal osmotic heat storage *vs* Sensible heat storage

To begin with, let us consider an upper limit in the amount of energy which could be stored by the thermal precipitation of common salts in comparison with sensible heat. This amount of energy will depend, of course, on the specific thermal dependence of the solubility of the given solution which not only may differ greatly between salts but also in the working range of temperatures allowable (see Fig. 2). Thus, for example, the extractable energy from $\mathrm{Na_2SO_4}$ could be perhaps around 1 kWh/m^3 , [5] and limited to a range of temperature around 300 K when the strong thermal dependence of the solubility disappear. On the other hand, another common salt as $\mathrm{KNO_3}$ features a stronger thermal dependence of the solubility with an extractable energy up to 5 kWh/m^3 or thereabouts and with a broad range of temperature.
As regard sensible heat, it is easy to see that sensible heat is able to store much more large amount of energy if one considers that, for example, water with a specific heat capacity $c_p \approx 1.16$ kWh/(m^{3}K) and with a temperature difference ΔT of, say, 20 K, will translate into a higher capability to store energy.
Nevertheless, the comparison is not so clear when besides the amount of energy stored it is also taken into consideration the total storing time as well as the compactness of the system as we will see below.

In order to perform a comparative study in which not only the amount of energy but also the storing time and compactness are considered, let us consider a cylindrical canister as depicted in Fig. 3. In this system, water (which is conspicuous by its high specific heat capacity) is stored at an initial temperature,

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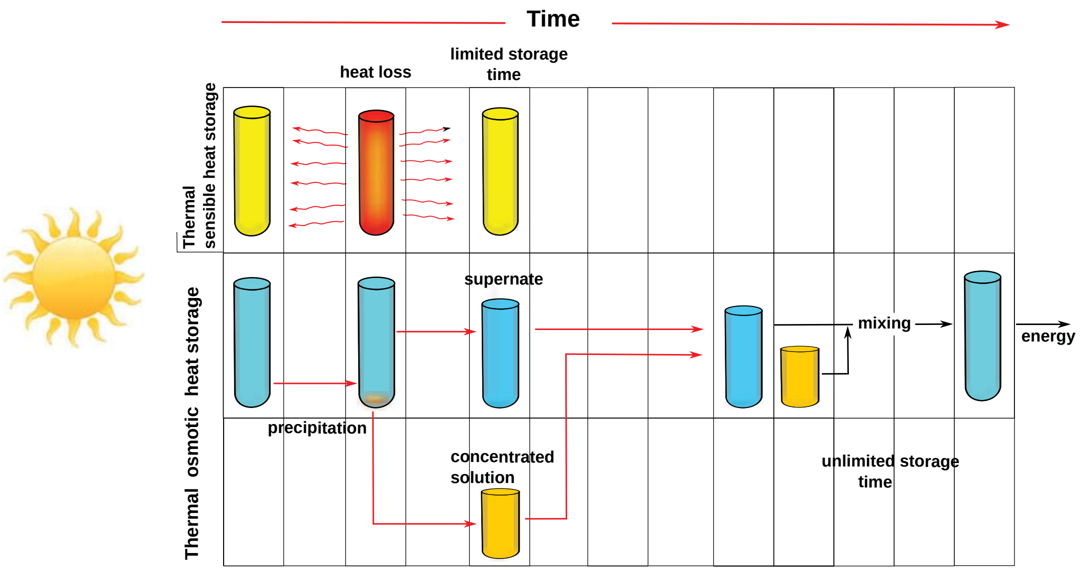

FIG. 1. Comparison between thermal sensible and thermal osmotic heat storage. Although the stored energy by sensible heat could be higher nevertheless the capability for storage is limited because the unavoidable losses with the environment. Contrariwise, osmotic energy can be stored indefinitely and only released when deliberately the two solutions are mixed.

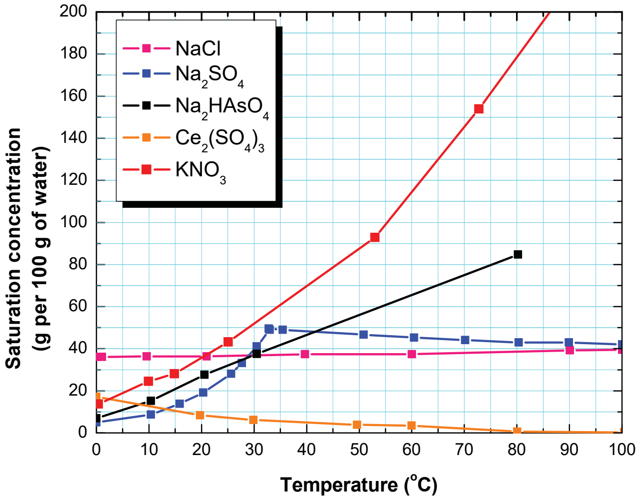

FIG. 2. Solubility vs. temperature for a variety of salts. .

say, T_i in the canister with radius r_1 and length l and thus containing a volume of water $\pi r_1^2 l$. This volume is isolated from the environment which is at temperature T_o by a second vessel with radius r_2 and an air-gap in between acting as insulator medium. For a preliminary reckoning, let us neglect axial heat losses in comparison with radial losses which translates into an overestimation of the capability of storing time of sensible heat and then a conservative safe approximation.

Under this conditions, the most simple model for the transient thermal conduction between the water and the environment is given by the well known lump expression

$$\frac{T(t) - T_o}{T_i - T_o} = e^{-\frac{t}{\tau}} \tag{1}$$

where τ is the so called *time constant* given by

$$\tau = \frac{\rho V c_p}{A h} \tag{2}$$

where ρ and c_p are the density and heat capacity of the material., respectively; V and A are the volume and the cross-sectional surface area, respectively; and h the heat transfer coefficient. Assuming that the only mechanism for heat transfer between the water and the environment is by thermal conduction, the heat transfer coefficient may be approximated as

$$\frac{1}{h} = \frac{r_2}{\kappa} \ln \frac{r_2}{r_1} \tag{3}$$

where κ is the thermal conductivity of the air, and r_1 and r_2 are the inner and outer radius, respectively. Under our conservative assumption of neglecting the axial heat transfer, we have that $\frac{V}{A} \approx \frac{r_1}{2}$ and then by inserting Eq.(3) into Eq.(2) one obtains

$$\tau = \frac{\rho c_p r_1^2}{2\kappa} \left[\frac{r_2}{r_1} \ln \frac{r_2}{r_1} \right] \tag{4}$$

The sensible energy stored per unit of volume $E_v(t)$ at a given time t is calculated from Eq.(1) and yields

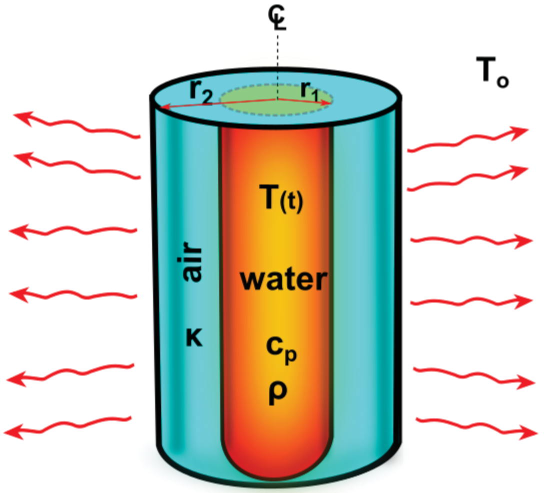

FIG. 3. Physical model for the transient thermal conduction between the water and the environment.

$$E_v(t) = (c_p \rho \Delta T) \cdot e^{-\frac{t}{\tau}} \tag{5}$$

where $\Delta T = T_i - T_o$ is the initial difference of temperature. Finally, by rearranging terms, we find the storing time as function of the final energy as

$$t = -\tau \ln \left[\frac{E_v}{\rho c_p \Delta T} \right] \tag{6}$$

Therefore, thermal osmotic storage could be an attractive option when the required storable time t is so large that the sensible heat drops below the magnitude of the energy able to be stored indefinitely by osmosis. If one takes this threshold of osmotic energy $E_\pi \approx 5$ kWh/(m^3) for a salt featuring a strong thermal dependence with solubility as is the case for KNO_3 we obtain that for a time larger than

$$t \approx -\tau \ln \left[\frac{5kWh/m^3}{\rho c_p \Delta T} \right] \tag{7}$$

osmotic thermal storage starts to be an attractive option.

• Discussion

In order to obtain some idea of the shape of the curves predicted by Eq.(7), we assume some typical values of the parameters using water as thermal fluid and a air as isolator: for water $c_p = 1.16$ Wh/(kg K); and $\rho = 10^3$ kg/m^3; for the air $\kappa = 0.025$ W/(m K). The resulting curves are shown in Fig. 4 and Fig. 5 for a canister with radius $r_1 = 5$ cm and $r_1 = 2$ cm as a function of the ratio between the radius of the isolator r_2 and the canister r_1 (see Fig. 3), $\frac{r_2}{r_1}$ i.e., the compactness of the system and with an initial $\Delta T = 80$ K. In those Figures the curve is given the time for a given compactness where the sensible heat in the canister drops just at the limit given by osmotic storing because the heat losses with the environment. For example, referring to Fig. 4, for a canister with 5 cm and a ration $\frac{r_2}{r_1} = 1.15$, i.e., with

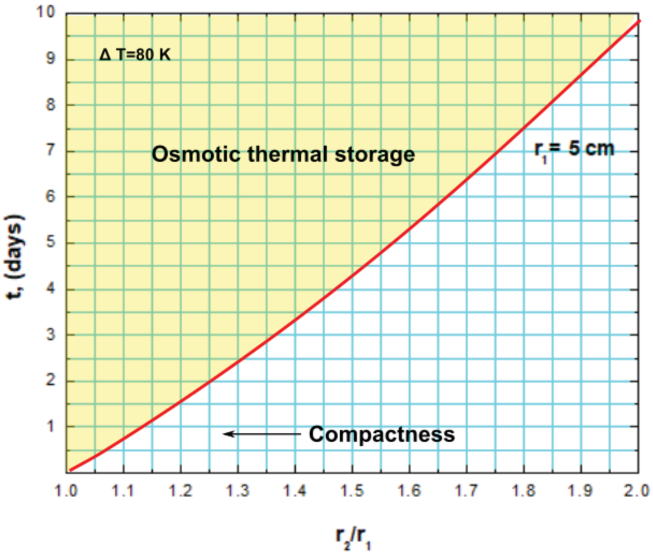

FIG. 4. Thermal storing time as a function of the ratio between the isolation chamber r_2 and the canister r_1 as depicted in Fig. 2, and for a canister with radius $r_1 = 5$ cm.

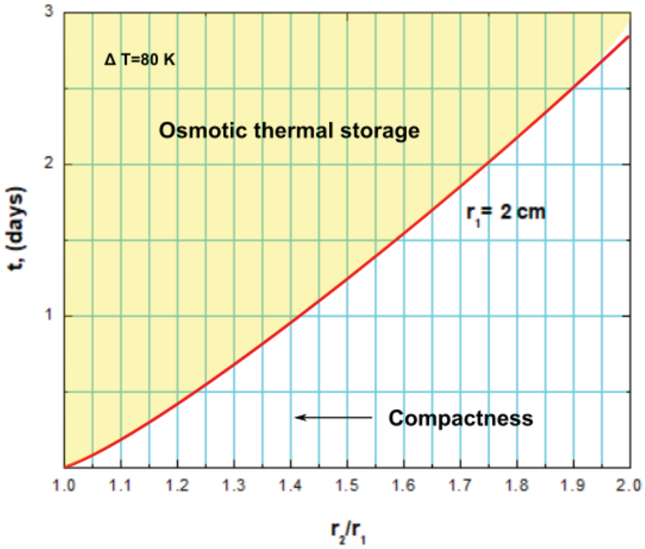

FIG. 5. Thermal storing time as a function of the ratio between the isolation chamber r_2 and the canister r_1 as depicted in Fig. 2, and for a canister with radius $r_1 = 2$ cm.

an air-gap $r_2 - r_1 = 6.0$ cm, the canaster will be only able to store energy higher than osmotic up to ≈ 4 days or thereabouts, if one wants more time it will necessary using a larger isolator. The compactness can be a limiting factor not only because the availability of space but also in terms of the cost of the overall system.

I. SUMMARY OF RESULTS AND CONCLUSIONS

In this note, a scoping study was performed in order to asses the attractiveness of osmotic thermal storage by harnessing the thermal dependence of common salts in comparison with sensible heat storage. Utilizing a simplified geometrical and transient thermal conductive model it was analyzed under what conditions the approach could be interesting. . It is shown that thermal osmotic storage via thermal precipitation of common salts could be an attractive option when long thermal storage (days) and compactness is desired. The interesting conclusions derived from this preliminary work are as follows:

(a) Sensible heat could store a larger amount of thermal energy per volume than that stored by osmosis.

(b) However, if storing time and compactness of the system is considered, osmotic thermal storage could be an attractive option.

(d) Additional R&D is required in order to arrive at a reliable practical and commercial design

Nomenclature

c_p = heat capacity
E = energy
h = heat transfer coefficient
t = time
T = temperature
r_1 = inner radius
r_2 = outer radius

Greek symbols

κ = thermal conductivity
ρ = density
τ = time constant

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