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A First Estimate for Thermal Osmotic Long Storage

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In this brief note, a first assessment on the possibilities for thermal osmotic storage using the thermal precipitation of aqueous solutions as alternative to sensible heat storage is performed. In a recent study it was found that the thermal dependence of the solubility of many common aqueous solutions could be harnessed to transform thermal energy into osmotic energy and then to run a heat powered cycle. Here, a scoping study is performed on the possibility to use such a property to storage thermal energy. Utilizing a transient model it was found that despite the fact that traditional sensible heat can stores much more thermal energy than osmotic does, however, for large Biot and Fourier numbers -which means compactness and long thermal storage, the osmotic storage becomes an attractive option. Additional R&D is required in order to arrive at a reliable practical and commercial design.

Keywords. *Sensible heat storage, Osmotic energy.*

1. Introduction

The object of this note was a first scoping study to compare and asses the attractiveness of thermal osmotic storage -by using the thermal precipitation of solute from aqueous solutions and the generation of two separated streams with two different salinities which can be stored indefinitely and releasing the osmotic energy only upon deliberated mixing, with traditional sensible heat storage. In a recent work, [1], it was discussed that because the thermal dependence of the solubility of aqueous solutions, it is possible to harness this feature to convert thermal energy into osmotic energy by using a proper process. However, in that early work, the thermal osmotic energy by using aqueous solution was intended to run powered heat cycles (osmotic heat engines), but the idea could be equally interesting for thermal storage in comparison with sensible heat. Fig.1 is a sketch of the thermal osmotic storage concept by thermal precipitation of aqueous solutions which will be discussed.

• Thermal osmotic heat storage *vs* Sensible heat storage

In terms of amount, sensible heat can potentially store larger amount of energy than osmotic does. For example, if one considers the case for water, with a specific heat capacity $c_p \approx 1.16$ kWh/(m^{3}K), then a temperature difference $\Delta T = 80$K , will translate into 92 kWh/(m^3), however, osmotic energy even assuming large salinity gradients can store around 5 kWh/(m^3) (per volume of solution) or thereabouts, [4]. However, the only advantage of osmotic energy is that it can be stored indefinitely and there would be no losses with the environment as occurs with sensible heat storage. Therefore, if it is pretended to find some attractiveness in osmotic storage in comparison with traditional sensible heat, it must be in terms of capability for long time storage as well as compactness of the container.

With this purpose in mind, there are two dimensionless numbers which can characterize transient heat conduction in terms of long time storage as well as compactness, namely, the Fourier number **Fo** and the Biot number **Bi**. The Fourier number **Fo** conceptually, it is the ratio of diffusive or conductive transport rate to the quantity storage rate and is given by

$$\mathbf{Fo} = \frac{\kappa t}{c_p \rho L^2} \tag{1}$$

where κ is the thermal conductivity; c_p the specific heat capacity, and ρ the density; t is the characteristic time; and L is the characteristic length of the system. Because the Fourier number depends on time, it will account the time for thermal storage. On the other hand, the Biot number **Bi** gives a simple index of the ratio of the heat transfer resistances inside of a body and at the surface of a body and is given by

$$\mathbf{Bi} = \frac{Lh}{\kappa} \tag{2}$$

where h is the heat transfer coefficient. It is easy to see that for our purpose, the Biot number gives account of the compactness of the system because it depend directly on the thickness of the isolator system. In fact, if we assume that the heat loss with the environment is only by conduction t by using an isolator with a thickness , say, δ, then the heat transfer coefficient is given by

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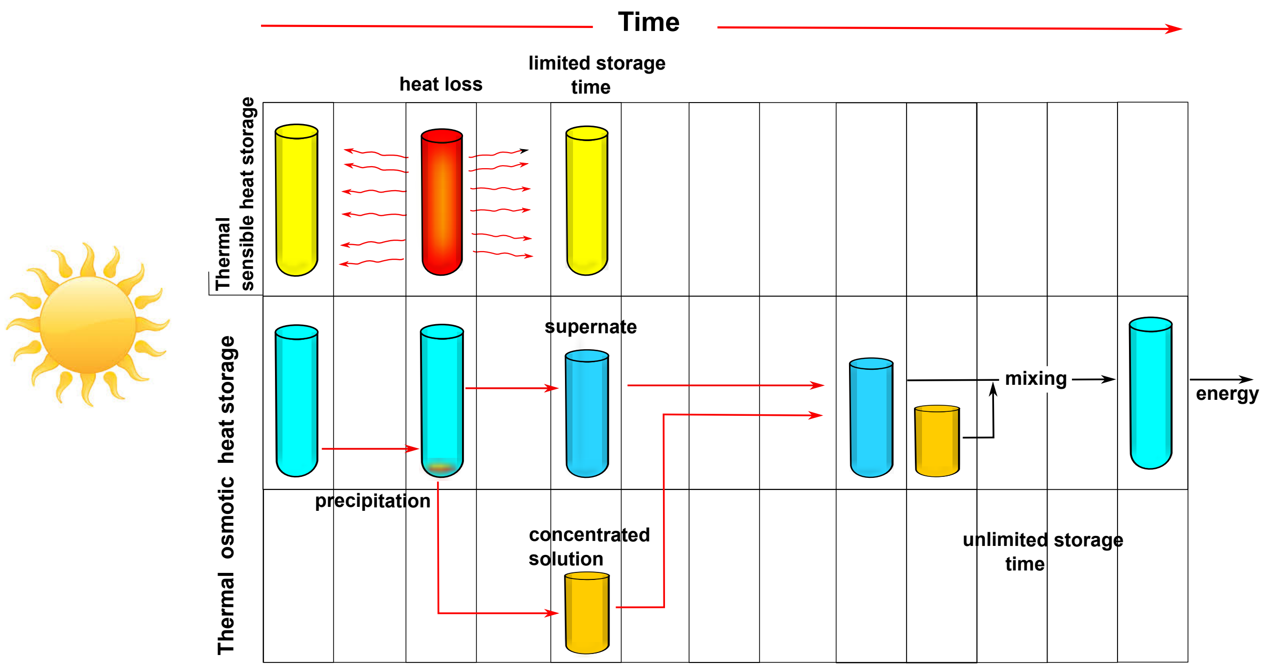

FIG. 1. Comparison between thermal sensible and thermal osmotic heat storage. Although the stored energy by sensible heat could be higher nevertheless the capability for storage is limited because the unavoidable losses with the environment. Contrariwise, osmotic energy can be stored indefinitely and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

$h = \frac{\kappa_i}{\delta}$ where κ_i and δ are the thermal conductivity and the thickness of the isolator. Thus Eq.(2 becomes

$$\mathbf{Bi} = \frac{\kappa_i}{\kappa}\frac{L}{\delta} \tag{3}$$

and it is easy to see that in this way the **Bi** number is related with the compactness of the system and more precisely inversely to the compactness. So, if one desires a compact system, the thickness of the isolator should be a small as possible, i.e., $\frac{L}{\delta} \to 0$ and then $\mathbf{Bi} \to \infty$. Conversely, if the thickness of the isolator is very large, the compactness is reduced, $\mathbf{Bi} \to 0$ and although it will store thermal energy for more time however this will be at the expense of compactness (and then increasing the cost of the system, e.g., larger containers, etc...). Therefore, long time storage as well as larger compactness, implies large Fourier numbers and large Biot numbers.

Many formulations for analysis of transient conduction based in those numbers are available in the literature, however, for the purpose of the present work, the graphical analysis tool for the evaluation of heat transfer in thermal engineering, due to Heisler, [2], seems preferable. Figure 2, shows the Heisler curve for the volumetric heat transferred from the wall Q_L (or lost heat with the environment) as a function of a dimensionless number $\mathbf{Bi}^2\mathbf{Fo}$ for an infinite cylinder, where Q_o represents the initial internal energy content per volume of the body in reference to the environment temperature, which is given by

$$Q_o = \rho c_p \Delta T \tag{4}$$

where $\Delta T = T_i - T_o$ is the difference of temperature with T_i is the initial temperature and T_o the environment temperature which is assumed to be constant.

In order to compare the sensible heat storage with osmotic storage, the Heisler´curves can be used as follows: First, if we call the osmotic energy per unit of volume which can be stored induced by the precipitation of solute from a given ΔT as Q_π, then the osmotic storage could be an attractive option in comparison with sensible heat storage only after a certain time from which the sensible heat stored drops (because unavoidable thermal loses with he environment) below the energy which can be osmotically stored indefinitely. Therefore, for a given energy stored as sensible heat Q_o osmotic storing starts to be more attractive when the following condition is accomplished

$$Q_o\left[1 - \frac{Q_l}{Q_o}\right] \leq Q_\pi \tag{5}$$

or

$$\frac{Q_l}{Q_o} \geq 1 - \frac{Q_\pi}{Q_o} \tag{6}$$

which considering Eq.(4) becomes

$$\frac{Q_l}{Q_o} \geq 1 - \frac{Q_\pi}{\rho c_p \Delta T} \tag{7}$$

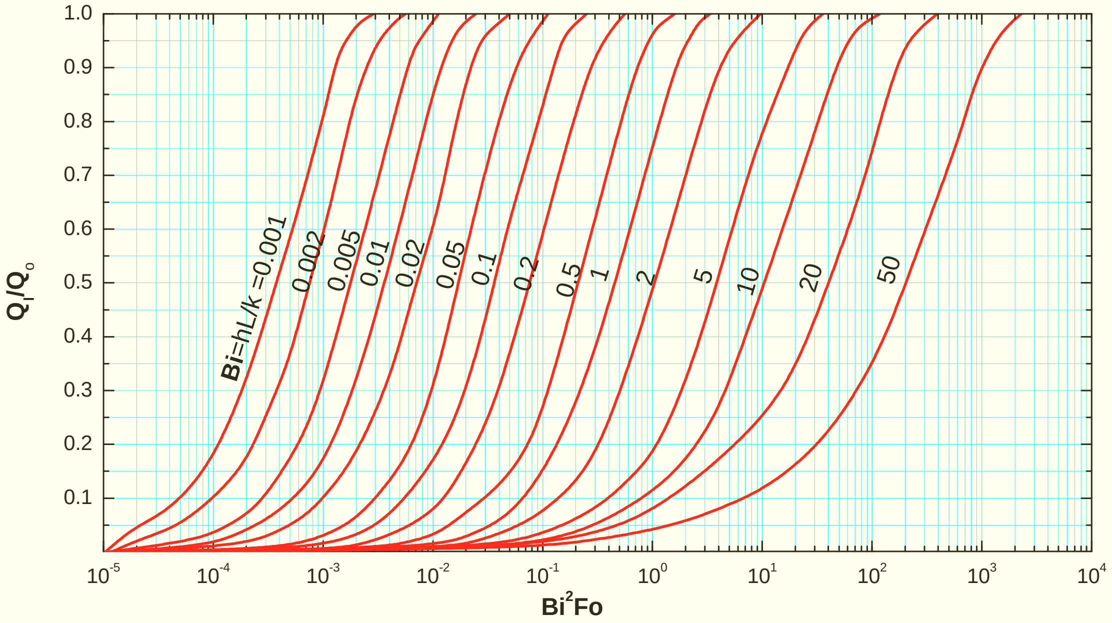

FIG. 2. Internal energy change for an infinite cylinder, [3].

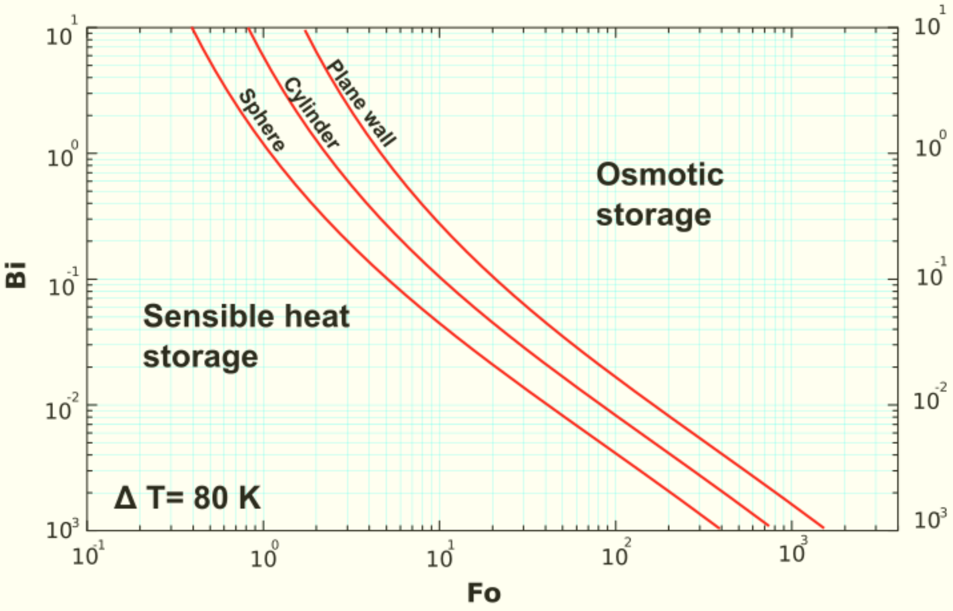

FIG. 3. Biot versus Fourier number transient heat transfer for a plane wall, infinite cylinder and sphere derived from Heisler curves as depicted in Fig. 2 and for a $\Delta T = 80$ K.

- **Discussion**

By using Eq.(7) and the Heisler´curves as plotted in Fig. 2, it is possible to obtain the region in which osmotic storage starts to be an option for heat storage if one knows the ΔT for sensible heat storage and the volumetric energy Q_π which can be osmotically stored using the same ΔT. As a manner of example, Fig. 3 gives the obtained curves for a plane wall, infinite cylinder and sphere using water with a $\Delta T = 80$ K, the osmotic energy which can be stored by precipitating the solute for a salt featuring a strong thermal dependence with the solubility and at that temperatures as KNO_3 can be around ≈ 5 kWh/(m^3) (cubic meter of solution), [1]. Referring to this figure, a cylindrical canister with a $DeltaT = 80$ K osmotic storage could be an option in comparison with sensible heat storage when it is desired a system with a, say, **Bi** $\geq 10^{-1}$ and a **Fo** $\geq 10^1$. For a canister with, say, a radius of 5 cm and using air as insulator media, by using Eq.(3) with $L = 10$cm, i.e., the diameter of the canister this translates into a insulator gap of 5.24 cm, and a time storage (calculated from Eq.(1) around 9.68

days or therabouts.

I. SUMMARY OF RESULTS AND CONCLUSIONS

In this note, a first scoping study was performed in order to asses the attractiveness of osmotic thermal storage using aqueous solutions rather than sensible heat storage. Some interesting conclusions are derived as follows:

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

(b) However, for large Biot and Fourier numbers which translate into compact and long storage units, osmotic storage could be an attractive option.

(c) Thermal osmotic storage for long and compact storage can find useful fields of applications when is desired compact and portable units able to provide with small inputs of energy and stored indefinitely for weeks or months.

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

Nomenclature

Bi = Biot number
c_p = heat capacity
Fo = Fourier number
h = heat transfer coefficient
L = characteristic length
Q = volumetric energy
t = time
T = temperature

Greek symbols

δ = thickness isolator
κ = thermal conductivity
ρ = density

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