# A FIRST STUDY INTO DESIGN ASPECTS FOR REACTORS FOR THERMOCHEMICAL STORAGE OF SOLAR ENERGY

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## Advantages of thermochemical storage

Traditional heat storage techniques have a number of disadvantages for long-term heat storage, such as substantial heat loss and relatively low energy density (large volume). As an alternative, it is possible to store energy by means of chemical processes, making use of the reversible chemical reaction $A + B \Leftrightarrow AB + heat$. Much of the early research on TCM storage was carried out in Sweden in the late ’70s (Oelert, 1982). Recently, there has been a revival in this research and the topic has received much attention in the IEA SHC task 32 (Hadorn, 2005). Interesting reactants are low cost, non-toxic, non-corrosive substances that have sufficient energy storage density and have reaction temperatures in the proper range. These requirements are fulfilled by a number of salt hydrates, in which A is the salt, B is water vapour and AB is a hydrated form of the salt. During summer, the hydrated salt is dehydrated by heat from a solar collector, which can be regarded as charging of the material. During winter, when heat is needed for e.g. residential heating, the salt is hydrated, producing heat. The vaporisation heat for the production of the water vapour is taken from the ambient (e.g. a borehole), which means that the system functions effectively as an absorption heat pump with a very large internal storage capacity of several GJ. Once the chemical reaction has taken place, the solar heat can be stored in this way for a long time period without losses.

## Reactor design for thermochemical storage

In a traditional sensible heat storage, heat can be extracted directly from the storage by a conventional heat exchanger. To discharge the heat of a thermochemical storage, the heat has to be generated first by letting an appropriate amount of the two components react with each other. After this, the heat has to be extracted from the material. If the heat storage is to be charged, an amount of the hydrated material has to be heated up and split into the two components. These components have to be stored separately, after which they cool down again to ambient temperature.

If a short-term storage is used, one may have the reaction take place inside the storage itself. However, if a seasonal storage is used, the total storage capacity required is very large compared to the amount of energy that is extracted from or fed to the storage in a day. If the reaction takes place in the storage vessel itself, a large amount of material is heated up, whereas only a small amount of material reacts, leading to large sensible heat losses at frequent on/off switching. Therefore, it is more efficient to apply a dedicated reactor that is separate from the storage itself.

## Simulation results

A first parametric study has been carried out in which the effects of a number of critical parameters in a TCM reactor system have been investigated, such as charging and discharging power, storage size and collector area required (for different collector types). Also, the effects of thermal capacity and TCM charge and discharge temperatures have been investigated.

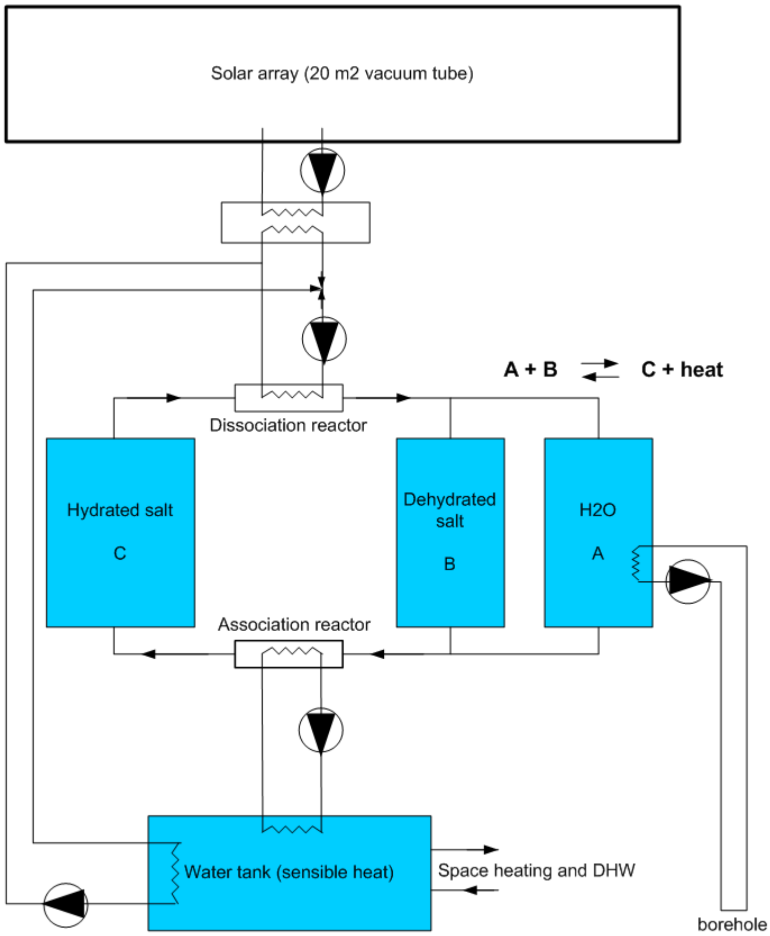


**Figure 1: Lay-out of the investigated system.**

The investigated system is shown in Figure 1. It consists of a vacuum collector array, a water tank, a TCM storage and a load.

For the demand, a low-energy house is assumed of 15 kWh/m$^2$ (passive house) and a total area of 110 m$^2$, resulting in a space heating demand of 1650 kWh (5.9 GJ). The tap water demand was assumed to be 9 GJ. The choice of a passive house is in agreement with the fact that one should first reduce the energy use by insulation and other passive measures, before solar measures are applied.

In the calculation, a number of simplifications was made. The most important of these is the use of an ideal flow-through heater, so stand-by losses are ignored and 100% efficiency is assumed. Also pipe losses were ignored, as well as the pumping energy for both the water circuit and the TCM circuit. Therefore, the results of the calculation should be interpreted as showing trends, rather than absolute values, and in a real system the solar fractions will be lower than the ones calculated here. The calculations were carried out for the Dutch climate, using the test reference year. For the collector efficiency, the values of Table 1 were used. Angular corrections for the collector reflection losses were ignored. The control was such that the water tank was preferentially loaded, and the TCM storage was loaded whenever the water tank was full. Whenever the water tank is below the setpoint temperature, the TCM storage starts charging the water tank, until the water tank reaches the setpoint temperature again or the TCM tank is depleted.

| | |
|---|---|
| Flat-plate collector | $\eta = 0.76 - 3.5 \times (Tin-Ta)/Gpy$ |
| Vacuumtube collector | $\eta = 0.68 - 0.86 \times (Tin-Ta)/Gpy - 0.0058 \times (Tin-Ta)^2/Gpy)$ |

**Table 1: Collector efficiency curves used**

The TCM storage itself was modelled as a black box with a certain storage capacity, a maximum limit for the charging and discharging power, and fixed values for the charge and discharge temperatures.

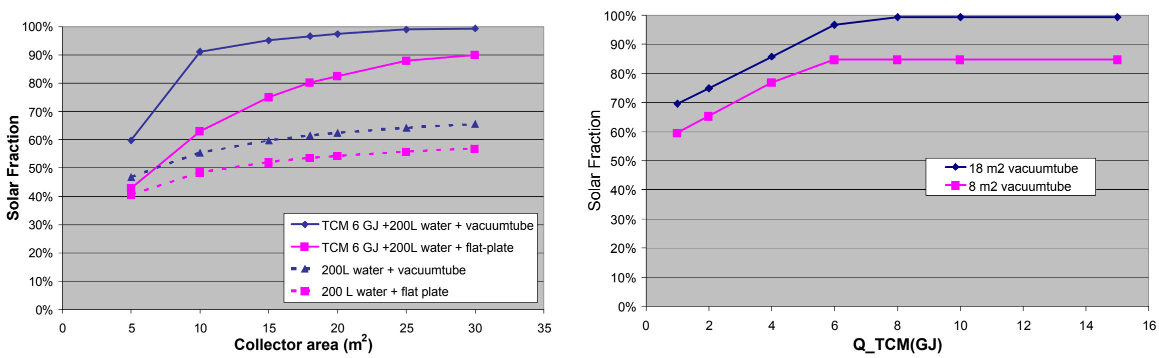


**Figure 2: Effect of collector area and TCM storage capacity on solar fraction**

Figure 2 shows that the use of a TCM storage strongly increases the solar fraction that can be obtained. For the presented system, the storage capacity should preferably be of the order of magnitude of the total space heating demand. The collector area should preferable be vacuum tube, since relatively high temperatures are required to charge the TCM material.

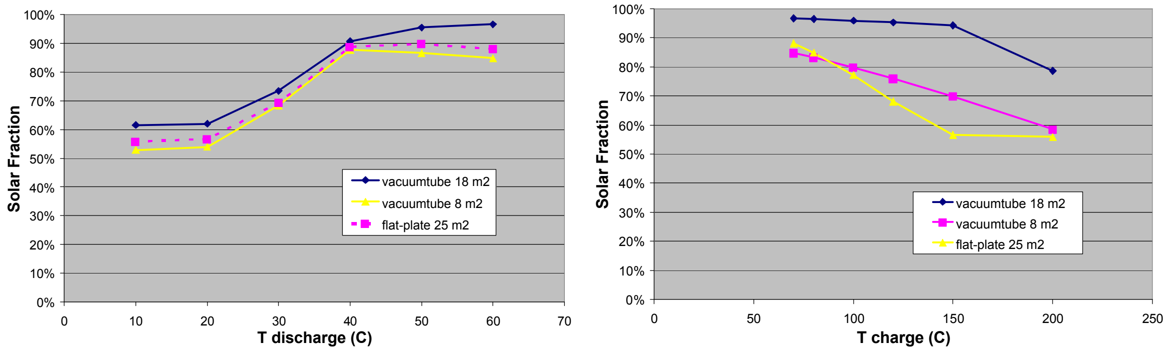


**Figure 3: Effect of charge temperature and discharge temperature on solar fraction.**

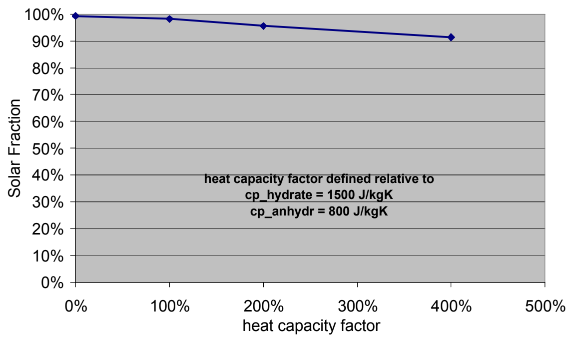


**Figure 4: Effect of TCM heat capacity on solar fraction**

Figure 3 and Figure 4 show the effect of various TCM material parameters. With respect to the TCM material, it can be seen that, to get a sufficient effect, the charging temperature should not be too high for the collector array, while the discharge temperature should not be too low to be able to use the heat. This allows for only a limited range of reaction enthalpy values for the TCM material. Figure 4 shows that for a separate reactor concept, the effect of heat capacity of the TCM material itself is small.

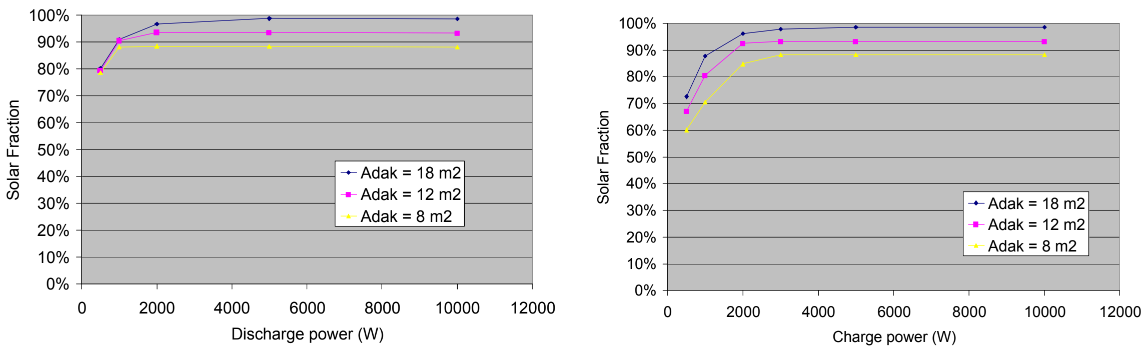


**Figure 5: Effect of charge power and discharge power on solar fraction**

With respect to the reactor design, one can see that the charge and discharge power should be of the order of 2-3 kW for an optimal system. In practice, since the thermal conductivity of TCM materials is generally low, this means that in the reactor design much effort should go into the optimization of the heat transfer.

## Reactor concepts

A relatively high reactor power is required in the order of 2-3 kW. Especially the hydration power is critical, since the hydration of a layer of material is a very slow process, due to the very low vapour pressures that are driving this reaction. Also for discharge, one has to be careful that the temperature gradients induced by the high power do not lead to local melting of the hydrated material before it is dehydrated. This means that both the heat transfer and the vapour transport though the reactor should be sufficiently good. Various options exist for reactor concepts that could comply with these demands:

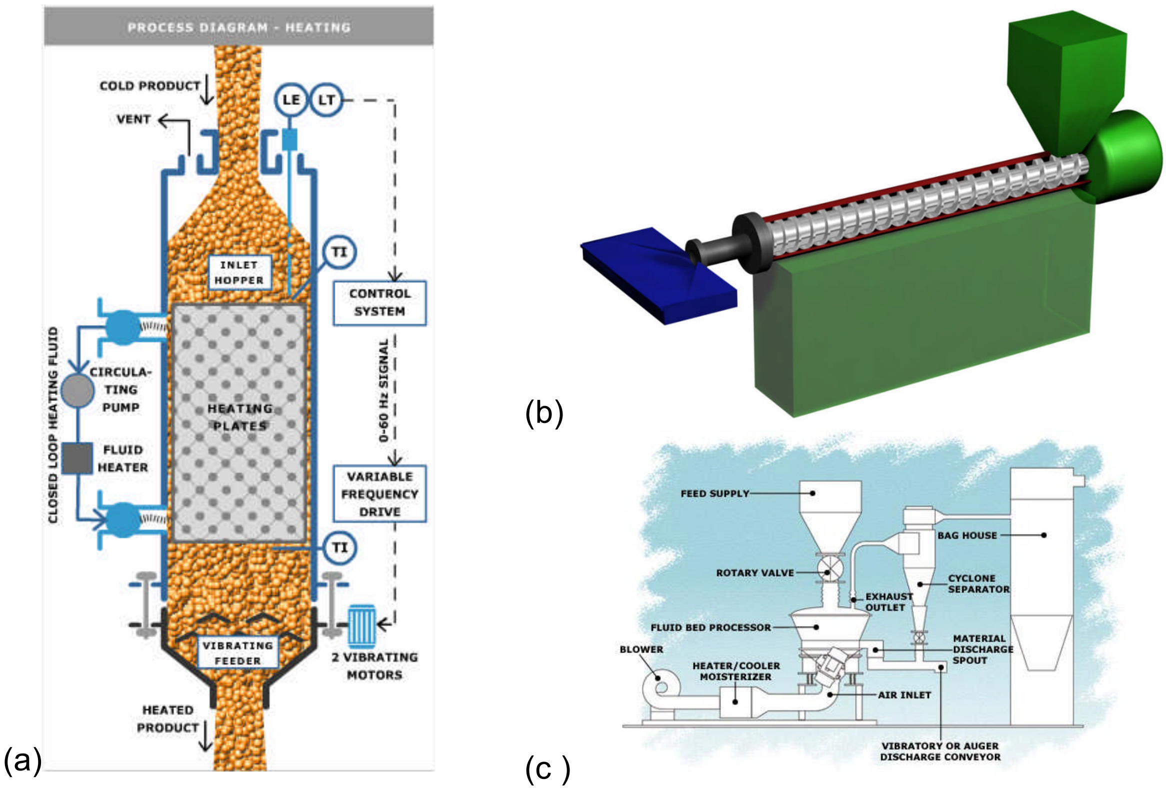


**Figure 6: reactor types (a) bulkflow (www.bulkflow.com), (b) screw reactor for plastics extrusion (wikipedia), (c) fluidized bed reactor (www.kason.com)**

- Screw reactor. These reactors are used e.g. for the extrusion of plastics. They have good heat transfer, but parasitic electricity use may be an issue.
- Fluidised bed reactor. These reactors are widely applied in the production of fuels and chemicals and have a very good heat and vapour transfer. A problem may be abrasion of the TCM particles; the particles may be reduced

to a fine powder that may be blown out of the fluidized bed reactor. Also the parasitic energy use and the additional volume may be an issue.

- Bulk flow reactor. These reactors are used e.g. for heating and cooling of chemicals or the drying of sugar (see www.bulkflow.com). This may be an interesting concept, especially if the reaction is slow. However, sticking of particles to the exchanger plates may be an issue and also the vapour transport will require attention, requiring dedicated vapour channels.

## Conclusion and outlook

A first-order system simulation was carried out to obtain first estimates of the design boundary conditions for a TCM reactor. The simulations showed that TCM storage is a very interesting means of creating a seasonal storage for solar heat. However, a number critical issues exist, such as finding suitable materials (reaction temperatures in the right range) and building an optimized TCM reactor that is able to produce sufficient power and has a limited temperature drop. Various reactor concepts are proposed in this paper.

For the future, the first prototypes will be developed based on the proposed reactor types. These will be used to study the functioning in practice in a more detailed way, which will lead to further optimized concepts. In addition, the characterisation of materials will be continued and the present system model will be improved to take into account the loss mechanisms that are now ignored.

## References


- Oelert et al (1982), Thermochemical heat storage State-of-the-art-report, report Swedish counsil for building research, Stockholm, Sweden.
- Hadorn (2005), Thermal energy storage for solar and low energy buildings, report IEA task 32.


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