SOLARUPDATE

VOL. 72 | DECEMBER 2020

Newsletter of the International Energy Agency Solar Heating and Cooling Programme

#SolarHeat
#SolarThermal
#SolarProcessHeat
#SolarCooling
#SolarDistrictHeating

In This Issue

www.iea-shc.org

IEA SHC & IEA ECES Collaboration Makes Advances in Thermal Energy Storage

Thermal energy storage is key for integrating renewable heat sources into an energy system --from domestic applications to district heating and from industrial applications to the power sector. The flexibility storage provides is necessary for the coupling of energy sectors. When higher temperatures, volume restrictions or very long storage periods come into play, new compact thermal storage technologies are needed, but so is more work on their development for the different energy sectors. It is this need that was the motivation for SHC Task 58/ECES Annex 33: Material and Component Development for Thermal Energy Storage – to further improve the storage materials and components based on a better knowledge of the underlying physics and chemistry.

The joint project, SHC Task 58/ECES (Energy Conservation through Energy Storage) Annex 33 on Material and Component Development for Thermal Energy Storage, achieved something remarkable – it drew experts from the fields of materials development, thermal storage component development, and system integration to work together for the past three years on thermal energy storage (TES) materials and components development.

The Task participants conducted work in four main fields 1) the definition of the proper boundary conditions for the development and integration of thermal energy storage technologies for different applications, 2) the development and characterization of novel thermal storage materials, 3) the definition and testing of reliable testing procedures to determine the performance of materials and components under application conditions and 4) the analysis of design aspects for thermal energy storage components.

Below are selected achievements from the four main fields of work, along with some key messages extracted from the activities.

General key messages from the work are:

- The collaboration in SHC Task58/ECES Annex33 between materials experts and application experts led to an improved understanding and therefore, accelerated development.
- Standards for measurement and reporting are prerequisites for constructive discussions and rapidly addressing challenges and advancing TES technologies.

Energy Relevant Applications

Part of the project's work aimed to define sets of boundary conditions for a number of applications, for instance the use of TES for domestic hot water. The challenge was to find the proper balance between having a small set of more general boundary conditions

continued on page 2

SHC Members

AUSTRALIA
AUSTRIA
BELGIUM
CANADA
CCREEE
CHINA
DENMARK
EACREEE
ECI
ECREEE
EUROPEAN COMMISSION
FRANCE
GERMANY
ISES
ITALY
NETHERLANDS
NORWAY
PORTUGAL
RCREEE
SACREEE
SLOVAKIA
SOUTH AFRICA
SPAIN
SWEDEN
SWITZERLAND
TURKEY
UNITED KINGDOM

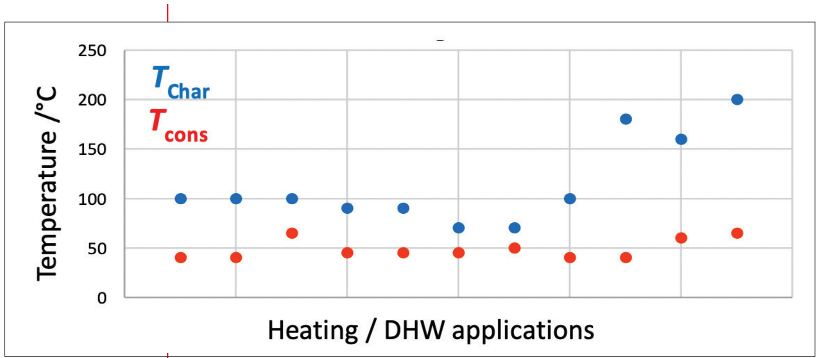
Thermal Energy Storage *from page 1*

that still reflect the details of individual technologies and having a larger set that better reflects the technologies but complicates the process of improving the materials and components for the technologies in an application. This problem was encountered especially in the field of industrial applications, as these show a very large variation. The most defining boundary conditions are the temperatures at which the storage is charged and discharged. In practice, this translates into a temperature that is available for charging, for instance from a solar thermal collector, and a temperature that is needed by the consumer, for instance for hot tap water. Figure 1 shows that these two temperatures have a variation over the different technological solutions applied by the experts.

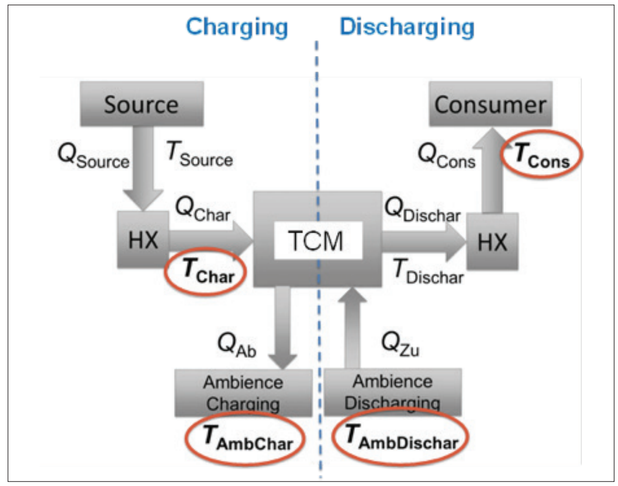
For thermochemical storage technologies, two other temperatures need to be specified. When charging, this is the temperature at which the sorbent is condensed. And when discharging, it is the temperature for evaporating the sorbent (see Figure 2.). This is particularly the case for seasonal storage, as these two temperatures will have very different values and need to be specified depending on the geographic location of the storage.

The key messages for this main field are:

- A large number of relevant applications exist for compact thermal energy storage.
- Standardized reference conditions can be defined for the building sector. For industrial applications, however, the diversity of processes makes it very difficult!



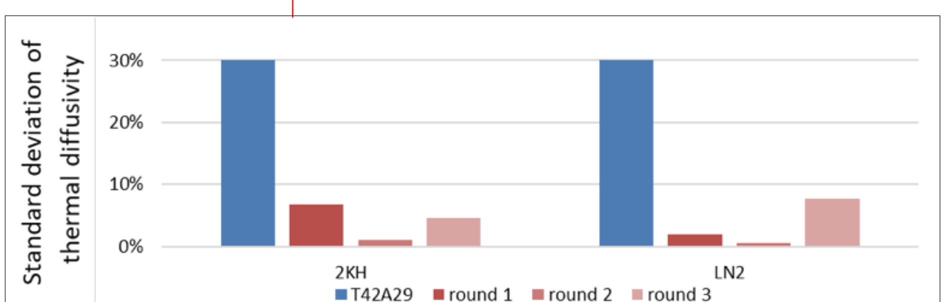
▲ Figure 1. Typical charging and consumption temperatures defined for 11 different compact thermal energy storage technologies, mostly using solar thermal collectors as the source.



▲ Figure 2. 4-Temperature Approach for thermochemical storage technologies. Besides the charging and consumption temperature, also the temperatures at which the sorbent is condensed and evaporated determine the storage performance and have to be specified.

Development and Characterization of Improved Phase Change Materials and Thermochemical Materials

Compact thermal energy storage technologies are based on either Phase Change Materials (PCM) or on Thermochemical Materials (TCM). PCM has been under development for a much longer time and already are applied in a large number of applications. As a result, the PCM development work in this project focused on improving the methods with which material characteristics can be determined. These characteristics, like thermal conductivity or viscosity, are needed for a better numerical simulation of the technologies, leading to better component design and improved component performance. Part of the work was to improve the quality of determining the thermal diffusivity of PCM. A number of laboratories performed measurements on samples of the same material, leading to a standard deviation between the results of the measurements that was considerable, see Figure 3. The experts then analyzed the possible causes for these deviations, both in the way the samples were prepared and in the measurement procedure. The



▲ Figure 3. Standard deviations of the differences between measured thermal diffusivity of a number of laboratories, for two different PCMs. The bars in blue show the values before the improvement of sample preparation and measurement procedure, the other colors the results after the improvements were implemented. The series on the left (with 2KH) were performed under cooling with 2 Kelvin per hour, while the series on the right underwent fast cooling with liquid nitrogen (LN2).

continued on page 3

improved sample preparation and measurement procedure were then tested and led to much lower deviations between the results from the different laboratories.

In the field of TCM, a large number of experts are working on the development of improved thermochemical materials. One TCM class is the combination of a salt hydrate with a porous material. Combining these materials leads to improved energy densities and better long-term performance. Salt hydrates, when taking up too much water vapor, can liquify, leading to a very poor performance. If the salt hydrate is impregnated into a porous material the liquefying is prevented, while the thermal storage capacity of the porous material is increased by the addition of the salt hydrate. Figures 4 and 5 show microscopic images of some sample materials and a graph of the energy densities of porous materials and novel developed composite materials. It can be clearly seen that the latter have a higher energy density.

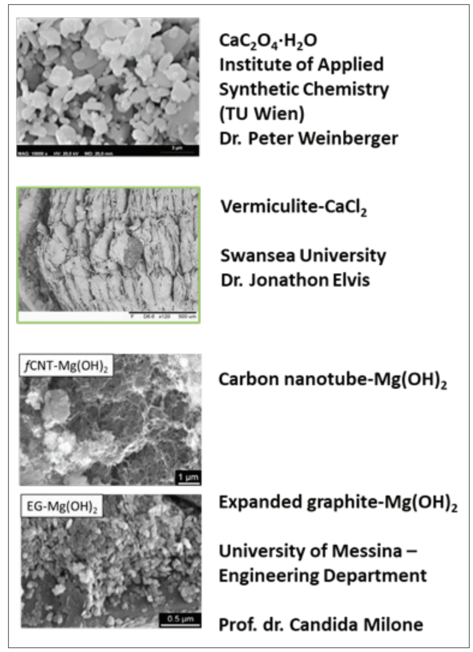
Work was also performed on the setting up of a materials database[2] with data on a number of materials for both PCM and TCM. This database will be expanded upon within the proposed follow-on SHC/ECES project.

Here, the key messages are:

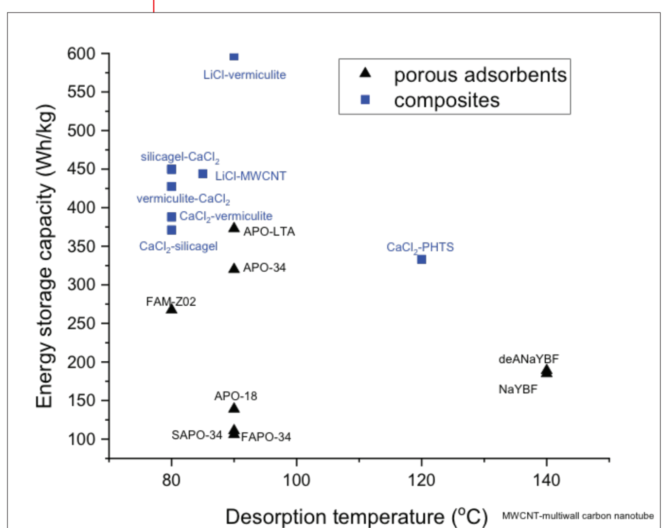
- A number of innovative and improved materials were developed and are continuously being developed, tested and introduced into storage components.
- Developed characterization methods are the basis for material evaluation and comparison and are the basis for the database inputs.
- The material properties not only cover the technical performance, but also questions like stability and compatibility.

Measuring Procedures and Testing Under Application Conditions

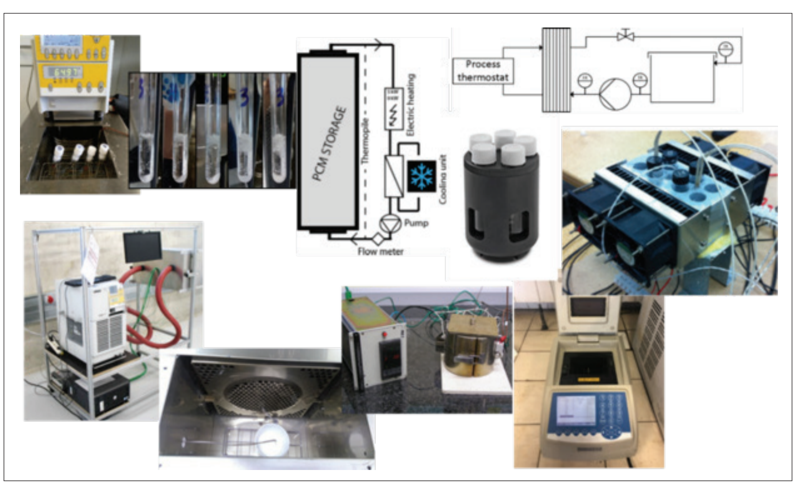
Ultimately, the performance of a thermal storage material is determined by it functioning in a component, in a system. So, when doing measurements on the storage material, one should apply the conditions imposed by the application. These are not only the temperature, pressure, humidity, etc. but also the geometry of a heat exchanger or the presence of other materials, for instance.



▲ **Figure 4. Microscopic images of different composite materials developed and tested by the project experts[1].**



▲ **Figure 5. Energy density of a number of materials. In black, the pure porous sorption materials and in blue novel developed composite materials.**



◄ **Figure 6. Experimental devices to investigate the long-term stability of PCM.**

continued on page 4

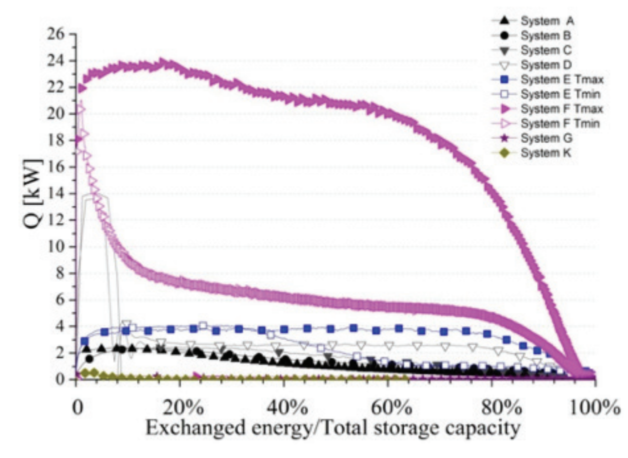
Material scientists characterize materials by performing measurements on a very small amount of material. This measured performance is mostly not identical to the materials' performance in a storage device. One would like to be able to connect the small-scale material characteristics with its performance on a larger scale, and the experts in this project worked on the first steps of this connection.

For PCMs, a vast amount of knowledge has been gathered on determining material performance on a small scale, and SHC Task 58/ECES Annex 33 started the work on defining measurement methods with which the bulk-scale behavior of PCM can be determined, like the degree of supercooling, phase separation and long term stability. For long-term stability, the different measurement devices and methods have been identified and described. In the proposed follow-on project, these will be compared to find out the weaknesses and strengths of the different methods and to improve the methods (see Figure 6).

For TCM, even the characterization on the small-scale level is leading to different results between different measurement methods. To find out what the causes are for the differences, a series of round-robin tests were designed and performed, both with a sorption material (zeolite 13X) and a salt hydrate (Strontium bromide hexahydrate). Both the conditioning procedure for the samples and the measuring protocol have been analyzed and proposal for improvement made. These will be used in a following round-robin to see whether the differences will decrease. For sorption enthalpy measurements on zeolite, this procedure has already led to smaller deviations in the results while the process for the salt hydrate is a bit more tedious and needs more work.

The key messages derived from this main field are:

- Only testing under application conditions helps in identifying the appropriate material for an actual application.
- Actual storage capacity and material stability have to be tested under real conditions and requirements.



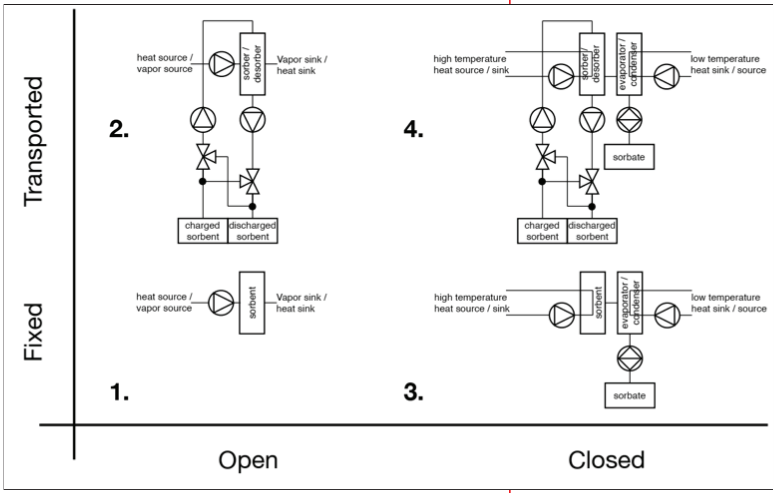
▲ **Figure 7. Normalized power/capacity curve of a number of PCM storage devices.**

Component Design for Innovative TES Materials

The main component for a PCM storage is the vessel/heat exchanger. The challenge in designing the heat exchanger is achieving the required thermal power in combination to a suitable energy storage density. In practice, there are many designs of heat exchangers for PCM. In this project, an inventory was made of PCM heat exchangers and then a method designed to determine the performance of the PCM in a uniform way, independent of design-specific aspects, see Figure 7. The aim is to compare different heat exchanger designs for a given application, helping to find the best design and a better understanding of interaction between thermal behavior of the PCM component and the material properties. A first set of normalized performance parameter was proposed[3], however further work will continue to explore most suitable normalization.

For TCM systems, the variety of component designs is very high, due to the difference in thermochemical storage principles. For low temperatures, for instance, there are sorption systems with solid material, salt hydrates systems with possible change from solid to liquid and liquid sorption systems that show crystallization under certain conditions. At higher temperatures, the variety is even stronger, with solid-gas reactions in which the solids also can melt or conglomerate. A first inventory of the different heat exchangers and reactors and the design of a classification method was completed, see Figure 8. These will form the basis for further component design and optimization in the proposed follow-on project.

To date, the evaluation and comparison between systems is practically impossible. Even when focusing on a single application, such as seasonal heat storage for space heating. The large variety of testing conditions hinders comparison. To resolve this issue, a literature study was performed, looking into the required temperature lift for desorption (GTLD), the resulting temperature lift in sorption (GTLS) and its ratio GTLS/GTLD, defined as temperature effectiveness (TE). This method describes how well the system takes advantage of the full potential of the employed storage material and enables a basic comparison between the systems as well as the basic process designs[4]. Further work will follow to define standardized testing conditions to evaluate progress in the field.



▲ **Figure 8. Basic description of investigated TCM storage processes.**

From this field, the following key messages are:

- Identification of component parameters is necessary to enable the comparison of compact storage concepts.
- The attainable charging/discharging power is strongly influenced by the component design, where the interaction of the storage material with the component is crucial.

Outlook

In the three years of the joint SHC Task 58/ECES Annex 33 project, important steps were made in improving the materials and testing methods for compact thermal energy storage technologies. And, first steps were made in understanding the interaction between storage material and the heat exchanger or reactor. But the challenges in using and improving the gained knowledge for a better designed component are big. In order to arrive at well performing, reliable and affordable compact thermal energy storage systems, these challenges will have to be tackled in a coordinated way and thus form the reason for the new proposed new project to further improve the test and characterization methods and the link between material performance on the lab scale and component scale by studying the material-component interaction in more detail. The adoption of novel techniques from the field of digitalization will be explored to help the materials development process and better determine the state-of-charge of a compact thermal energy storage device. All this though is dependent on the continuation of the very successful formula – close collaboration between material scientists and component and system design engineers.

This article was contributed by Wim van Helden, AEE INTEC, Austria, Alenka Ristic, NIC, Slovenia, Stefan Gschwander, FhG-ISE, Germany, Christoph Rathgeber, ZAE Bayern, Germany, Daniel Lager, AIT, Austria, Ana Lazaro, University of Zaragoza, Spain, Benjamin Fumey, EMPA, Switzerland.

1 Ristić, A., Zabukovec Logar, N., New composite water sorbents CaCl2−PHTS for low-temperature sorption heat storage: determination of structural properties. Nanomaterials, Jan. 2019, 9(1), 1-16

Krajnc, A., Varlec J., Mazaj, M., Ristić, A., Logar, N.Z., Mali, G., Superior Performance of Microporous Aluminophosphate with LTA topology in solar-energy storage and heat reallocation, Adv. Ener. Mat., 2017, 7, 201601815-1.

Ristić, A.; Fischer, F.; Hauer, A.; Logar, N. Z., Improved performance of binder-free zeolite Y for low-temperature sorption heat storage. Journal of Materials Chemistry A 2018, 6 (24), 11521-11530.

Rouhani, M., Kouchachvili, L., Djebbar, R., Bahrami, M., (2019) "Thermochemical energy storage for residential applications", 5th Experts meeting of IEA SHC T58/ECES A33, Ottawa, Canada.

Frazzica, A., Brancato, V., Caprì, C., Cannilla, C., Gordeeva, L.G. , Aristov, Y.I., Development of "salt in porous matrix" composites based on LiCl for sorption thermal energy storage, Energy, 208, 2020, 118338.

Brancato, V., Frazzica, A., Characterisation and comparative analysis of zeotype water adsorbents for heat transformation applications, Sol. Ener. Mat. Sol. Cells, 2018, 180, 91-102.

Brancato, V., Gordeeva, L.G., Grekova, A.D., Sapienza, A., Vasta, S., Frazzica, A., Aristov, Y. I. , Water adsorption equilibrium and dynamics of LiCl/MWCNT/PVA composite for adsorptive heat storage, Sol. Ener. Mat. Sol. Cells, 193, 2019, 133-140

2 www.thermalmaterials.org

3 A. Lázaro, M. Delgado, A. König-Haagen, S. Höhlein, G. Diarce: Technical performance assessment of phase change material components. In: SHC 2019 International Conference on Solar Heating and Cooling for Building and Industry, 2019

4 Fumey B., Weber R., Baldini L., Sorption based long-term thermal energy storage – Process classification and T analysis of performance limitations: A review, Renewable and Sustainable Energy Reviews 111 (2019) 57–74