International Energy Agency

Technology Collaboration Programme on Energy Storage

(ES TCP)

Task 40

Compact Thermal Energy Storage – Materials within Components within Systems

Executive Summary

Submitted for

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Task 40 is a fully joint Task with Task 67 of the IEA Solar Heating and Cooling TCP

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CONTENT

LIST OF ABBREVIATIONS

CTES	Compact Thermal Energy Storage
ES	Energy Storage
PCM	Phase Change Material
RRT	Round Robin Test
SHC	Solar Heating and Cooling
SoC	State of Charge
TCM	Thermochemical Material
TES	Thermal Energy Storage

MAIN RESULTS IN A NUTSHELL

Thermal energy storage (TES) is subdivided into sensible, latent, and thermochemical heat & cold storage. In Task 40, compact thermal energy storage (CTES) materials and components for latent heat & cold storage (phase change materials, PCM) and for thermochemical heat & cold storage (TCM) were in focus. A variety of different material classes is investigated and applied to be used as PCM and TCM in TES systems. New materials, material mixtures, and composites are worked on by a growing community of scientists.

TES components like heat (and mass) exchangers are used to charge and discharge TES units meeting application requirements. Due to the variety of different TES materials, different component concepts are being developed and tested. To enable a performance assessment of components, testing protocols need to pay attention to the material-component interaction.

Task 40 aimed to push forward CTES technology development to accelerate the market introduction through the international collaboration of experts from materials research, components development and system integration, as well as industry and research organisations.

The overall objectives were

1) to better understand the factors that influence the storage density and the performance degradation of CTES materials,
2) to characterize these materials in a reliable and reproducible manner,
3) to develop methods to effectively determine the state of charge of a CTES system, and
4) to increase the knowledge base on how to design optimized heat exchangers and reactors.

Task 40 was divided into five Subtasks. In Subtask A, *Material Characterization and Database*, standardized measurement procedures for CTES materials were developed and validated, and a materials & knowledge database was revised and maintained. In Subtask B, *CTES Material Improvement*, proper strategies that allow for tuning CTES materials' properties to improve their performance in components and systems were identified and analysed. In Subtask C, *State of Charge Determination*, techniques with which the state of charge of a CTES system can be determined in a reliable and cost-efficient way were collected and discussed. The objective of Subtask D, *Stability of PCM and TCM*, was to support R&D on PCM and TCM stability by understanding and classifying the underlying degradation mechanisms. The topic of Subtask E, *Effective Component Performance with Innovative Materials*, was the (evaluation of) material-component interaction for improved system performance.

Task 40, as it was with its predecessors, is built upon a strong collaboration within the international CTES R&D community. The following outcomes were achieved in the five Subtasks.

- Task 40 experts achieved substantial progress in working on standardized measurement methods leading to improved TES material characterization skills of the participating researchers and labs. To this end, round robin tests on thermal conductivity/diffusivity, specific heat capacity of powdery materials, enthalpy change due to sorption or chemical reaction, density, and viscosity were performed. The requirements of a revised CTES material database were defined, evaluated, and summarized in a software requirement specification (SRS) document.
- The information collected regarding CTES material improvement demonstrates how complex the study of these materials is, but also how proper strategies – like material mixtures and composites – allow to obtain materials with tuned properties for potential use in CTES

applications. Open questions cover the definition of guidelines for materials optimization and the quantification of the impact on the TES system.

- A total of twenty-six methods and proofs of concept to effectively determine the state of charge of PCM or TCM systems were collected and classified. Four prototype systems, where a direct interaction of material bulk response with the control system is in place, are presented and discussed.
- The developed approach to map degradation of CTES materials provides a comprehensive overview of the degradation mechanisms and the corresponding degradation factors which are relevant for a specific material or material class. Eleven different examples of CTES materials degradation mapping were elaborated. CTES material stability tests under application conditions can only be carried out reasonably if there is an understanding of the dependencies between degradation factors, degradation mechanisms, and effects on the CTES material and system.
- Performance indicators for PCM allowing a fair comparison of latent heat thermal energy storage units were proposed. This has not been possible so far. For example, a comparison of the average thermal power is strongly influenced by the initial and boundary conditions during the experiment. Three methods were developed by the Task participants to minimize these influences and enable a comparable analysis. For TCM component evaluation, a standardized absorption curve-based performance mapping and a standardized temperature-based test procedure for the sorption heat storage in space heating application were developed.

To disseminate the Task work, Task experts published a technology position paper [1] providing an overview of the compact thermal energy storage technologies market, outlining its importance, potential, and development. The paper addresses policy, decision makers, and influencers and aims to present high-level information as a basis for uptake and further development. It concludes by highlighting actions needed to further exploit thermal energy storages with minimal space requirements and accelerate more efficient energy systems, including sector coupling, with a higher share of renewables.

The work within this Task and its predecessors is establishing the foundation to focus on specific application areas for thermal energy storage. The investigation of the various aspects of material-component interaction is considered as a crucial part of the development and realization of CTES applications.

[1] SHC Technology Position Paper “Compact Thermal Energy Storage”, June 2023, [available through SHC Task 67 website.]

KEY MESSAGES

General

- Collaboration between material and application experts leads to an improved understanding of material and component design strategies and supports the development of CTES systems.
- Standards to measure material properties and to evaluate components are a prerequisite for constructive discussions among experts and for advancing CTES technologies.

CTES material characterization

- Developed experimental characterization methods (thermal conductivity/diffusivity, specific heat capacity of powdery materials, enthalpy change due to sorption or chemical reaction, density, and viscosity) are the basis for TES material evaluation and comparison.
- Applying a defined uncertainty evaluation according to standards (e.g. ISO/IEC Guide 98-3:2008) is important to develop measurement standards through round robin tests.

CTES material improvement

- A number of innovative and improved CTES materials, e.g. based on material mixtures and composites, were developed and continuously are being developed by the R&D community.
- The definition of guidelines for materials improvement and related KPIs for material performance assessment are a key aspect to guide material development strategies towards system requirements.

State of charge determination

- In flexible heating and cooling systems, *thermal batteries* are needed: TES systems with instantaneous State of Charge (SoC) determination.
- State of charge is a component property (not material) - analogy: electrical battery.
- Reliable SoC determination, based on material bulk response measurements, enables the integration of CTES systems into (digitalized) energy systems.

CTES material stability

- Understanding CTES stability on material level is essential to assess the (long-term) performance of CTES materials in components and storage systems.
- The developed degradation mapping offers an easy-to-use visualization of CTES material stability, thereby supporting the process of CTES material selection under application conditions.

CTES material-component interaction

- The reachable charging/discharging power is strongly influenced by the component (heat exchanger, reactor) design, where the interaction of the CTES material with the component is crucial.
- Uniform test schemes for component evaluation are being established to compare CTES system performance.

EXECUTIVE SUMMARY

1 Short Description of Task 40

1.1 Objectives and Scope

Task 40 dealt with an application-oriented development of innovative and compact thermal energy storage (CTES) materials: Phase Change Materials (PCM) and Thermochemical Materials (TCM). PCM and TCM are studied, improved, characterized, and tested in components. The main components for CTES technologies are heat exchangers and reactors.

The objectives were to have a better understanding of the factors influencing the energy storage density and the performance degradation of CTES materials, to be able to characterize these materials in a reliable and reproducible manner, to have methods to effectively determine the state of charge of a CTES unit, and to have better knowledge on how to design optimized heat exchangers and reactors.

1.2 Organisational Structure

IEA ES TCP Task 40 is a fully joint activity with IEA SHC TCP Task 67.

The work of the Task was split into five Subtasks.

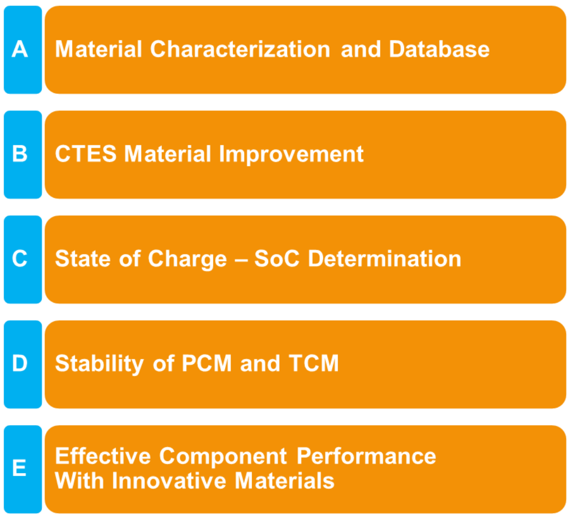

Figure 1-1: Subtask structure.

The Subtask leaders were:

- Subtask A: Daniel Lager, AIT, Austria
- Subtask B: Stefania Doppiu, CIC energiGUNE, Spain
- Subtask C: Gerald Englmair, DTU, Denmark, and Reda Djebbar, NRCan, Canada
- Subtask D: Christoph Rathgeber, ZAE Bayern, Germany
- Subtask E: Ana Lazaro, Univ. Zaragoza, Spain, Andreas König-Haagen, Univ. of the Basque Country, Spain, and Benjamin Fumey from HSLU, Switzerland

1.3 Duration of Task

The beginning of Task 40 was 1 July 2021 and the end 30 June 2024. The work plan was approved by the ES TCP Executive Committee at the 91st ExCo meeting on 7–8 June 2021. It was confirmed by the participants at the kick-off meeting on 27–29 October 2021.

1.4 Experts Meetings

Table 1-1 gives an overview of the expert meetings in this Task.

Table 1-1: Details about the date and location of each expert meeting.

City	Country	Date	# Participants
Vitoria-Gasteiz	Spain	27–29 October 2021	53 (24 on site, 29 online)
Graz	Austria	4–5 April 2022	38 on site
Kassel	Germany	29–30 September 2022	41 on site
Halifax	Canada	24–26 April 2023	37 (30 on site, 7 online)
Lyon	France	2–4 October 2023	35 (29 on site, 6 online)
Lucerne	Switzerland	22–24 April 2024	32 (24 on site, 8 online)

1.5 Participation

Table 1-2 gives an overview about which institution from which country is participating in this Task.

Table 1-2: List of participating institutions and experts per country.

Country	Institution	Representative (name)
Austria	AEE	Wim van Helden, Franz Hengel
Austria	AIT	Daniel Lager, Fabrizia Giordano
Austria	FHOÖ	Gayaneh Issayan, Bernhard Zettl
Austria	TU Wien	Peter Weinberger, Jakob Smith, Frieda Kapsamer
Canada	Dalhousie University	Dominic Groulx
Canada	NRCan	Reda Djebbar, Lia Kouchachvili, Dylan Bardy
Canada	University of Ottawa	Handan Tezel
Canada	Neothermal ES Inc	Louis Desgrosseilliers
Denmark	Aalborg University	Alireza Afshari, Alessandro Maccarini
Denmark	DTU	Gerald Englmair, Jianhua Fan
France	INSA Lyon	Frédéric Kuznik, Kévyn Johannes
France	CNRS	Jerome Soto
France	CEA LITEN	Grégory Largiller
France	LOCIE Laboratory	Èlise Bérut
France	Université d'ARTOIS	Laurent Zalewski
France	Université de Nantes	Lingai Luo
France	University Savoie Mont Blanc	Nolwenn Le Pierrès
Germany	CAE	Michael Brütting
Germany	ZAE Bayern	Andreas Hauer, Christoph Rathgeber
Germany	DLR	Anthony Rawson, Andrea Gutierrez, Maike Johnson, Veronika Stahl, Peter Vetter, Larissa Dietz
Germany	Fraunhofer ISE	Stefan Gschwander, Franziska Klünder, Wenye Lin, Sebastian Gamisch

Germany	TU Munich	Leander Morgenstern, Florian Kerscher
Germany	-	Harald Mehling
Italy	CNR	Vincenza Brancato, Andrea Frazzica
Italy	University of Messina	Luigi Calabrese, Elpida Piperopoulos, Emanuela Mastronardo, Candida Milone
Netherlands	PLUSS Polymers	Nidhi Agarwal
Netherlands	TNO	Ruud Cuypers
Netherlands	TU Eindhoven	Henk Huinink
Netherlands	University Twente	Mina Shahi
Norway	SINTEF	Jorge Salgado Beiceiro, Olav Galteland, Alexis Sevault
Portugal	Polytechnic Institute of Setúbal	Luis Coelho
Portugal	University of Coimbra	José Costa, Adélio Gaspar, Marco Fernandes
Slovenia	National Institute of Chemistry	Alenka Ristić
Slovenia	University of Ljubljana	Urška Mlakar
Spain	University of Barcelona	Ines Fernandez, Camila Barreneche
Spain	CIC energiGUNE	Jean-Luc Dauvergne, Elena Palomo del Barrio, Eduardo Jose Garcia-Suarez, Stefania Doppiu, Ángel Serrano
Spain	CIEMAT	Rocio Bayon, Oscar Seco Calvo
Spain	Universidad del País Vasco UPV/EHU	Ane Miren García Romero, Andreas König-Haagen, Gonzalo Diarce
Spain	University of Zaragoza	Ana Lazaro
Spain	University of Lleida	Luisa F. Cabeza, Gabriel Zsembinszki, Emiliano Borri, David Verez
Sweden	KTH	Saman Gunasekara
Switzerland	HSLU	Benjamin Fumey, Rebecca Ravotti, Yannik Krabben, Jörg Worlitschek
Turkey	Cukurova University	Halime Paksoy
United Kingdom	Loughborough University	Phil Eames
United Kingdom	University Birmingham	Yulong Ding
United Kingdom	University of Warwick	Bob Critoph, Sai Saran Yagnamurthy
United Kingdom	Swansea	Jonathon Elvins, Sara Walsh, Jack Reynolds, Sahand Hosouli
United States	US DoE	Sven Mumme, Sumanjeet Kaur

2 Summary of Subtasks

2.1 Subtask A: Material Characterization and Database

The main objective of Subtask A was to develop and/or validate several standardized measurement procedures for TES materials based on PCM and TCM and to further maintain the existing TES material database.

2.1.1 Standardized measurement procedures and round robin tests

In the preceding TES materials Tasks, new TES materials were identified or developed in research projects of the participating partners. Furthermore, measurement procedures were developed to identify the main physical or chemical parameters. Some of these procedures were already validated and some of them were still at the beginning. In Task 40, round robin tests (RRT) on (i) thermal conductivity and diffusivity, (ii) specific heat capacity, (iii) sorption enthalpy, as well as (iv) density and viscosity of different PCM and TCM were conducted. Depending on the material type and measurement method, different measurement procedures were developed, tested, and evaluated to receive comparable results among the round robin participants. Overall, more than forty organizations from sixteen countries participated in the round robin tests.

The summarized lessons learned from the round robin tests are:

- The equipment variability supposes a challenge to establish a standardized measurement protocol and needs more effort in the beginning of a round robin test.
- Analysis of measurement uncertainty needs to become part of the lab routine. Experimental and systematic uncertainty must be accounted to compare the final results. In some cases, the uncertainty reported was below the equipment error, due to
    - not enough repetitions,
    - not accounted for equipment error,
    - or not enough samples tested.
- The occurrence of water in the sample (especially for TCM, e.g. hydrated or sorption samples) can lead to different sample states in the beginning of the measurement and should be examined in more detail before the measurement.
- It is challenging to have enough participants with comparable instruments participating; meaningful results are only possible with an adequate number of participants.
- Sample preparation and instrument calibration are crucial and to be exercised.

As an example, Figure 2-1 shows the comparison of measured densities of a paraffin melting between 53 and 58 °C. While the liquid densities were in sufficient agreement, the solid densities showed significant deviations. Therefore, the sample preparation and measurement procedure in the solid state was discussed in more depth by the participating experts.

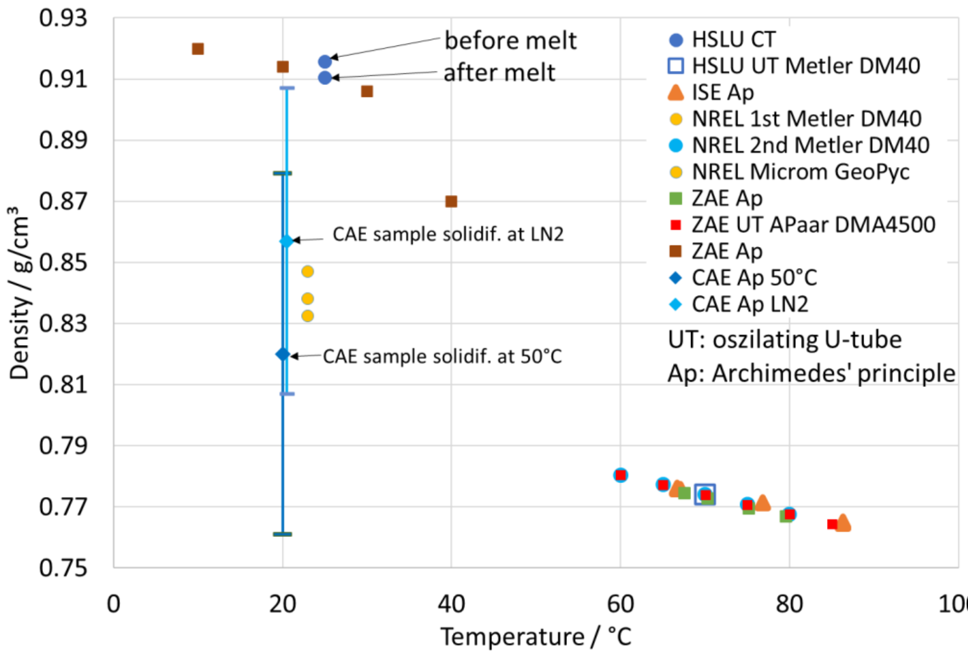

Figure 2-1: Comparison of results of the density RRT.

Summarizing the common topics for future activities:

- An increased number of participants for the round robins to get statistic significant results.
- A defined uncertainty evaluation for all round robin tests according to standards (e.g. ISO/IEC Guide 98-3:2008)
- Exploring new PCM and TCM:
  - Adapt sample preparation procedures for hydrated or sorption materials.
  - Measure PCM with non-Newtonian behaviour in the liquid phase.
- Apply and adapt the methods for high temperature TES materials.

During this Task, round robin test results and improvements for all above mentioned quantities were achieved. The detailed results and measurement procedures can be found in the section 3.1 of the final report.

2.1.2 CTES Materials database and knowledge platform

In the second activity of Subtask A, the requirements of a new *Thermal Energy Storage Material Database* were defined and evaluated. A database has already been developed in the previous Tasks (https://thermalmaterials.org/). This database is to be filled with new data and structurally adapted in the future. One of these structural changes is the link to existing databases such as the *slPCMlib* (https://slpcmlib.ait.ac.at/) database. Several changes of the existing database were proposed to the experts of Subtask A and assessed based on a survey. A *Software Requirement Specification* (SRS) document was created from this survey. The SRS summary is given in section 3.2 of the extended final report and the complete SRS can be found in Appendix 8.1.

Due to budgetary constraints, it was not possible to proceed with the development of an offer from any of the software development firms contacted. Therefore, it was not possible to complete the implementation of the new version of the database.

An outcome for a future task is to implement a reduced number of requirements, while contacting a larger number of software development firms. For this purpose, the developed SRS document constitutes a solid basis to start from, as it follows the conventional IT requirements format needed for database platform development. Starting from the SRS document, the requirement specifications could be further refined to produce an optimized selection that fits within the available budget for the development of the database.

2.2 Subtask B: CTES Material Improvement

The objective of Subtask B was to identify strategies for tuning the properties of CTES materials to improve their performance in components and storage units. This included to discover new potential materials for CTES with the targets of low cost, no toxicity, non-flammable, deployment of natural/bio-based materials; to develop single component materials with changed chemistry through modified structure and multi-component materials with increased storage capacity and enhanced heat and mass transport properties; to evaluate the influence of the synthesis and processing methods on the techno-economic and environmental performances of the materials.

The following CTES materials were considered in Subtask B.

- PCM: solid-liquid and solid-solid transitions, composites and shape-stabilized materials.
- TCM: sorption processes (ad- and absorption) and chemical reactions (mainly gas-solid).

An overview of the CTES materials, the R&D objectives with respect to materials improvement, and possible pathways is given in Figure 2-2.

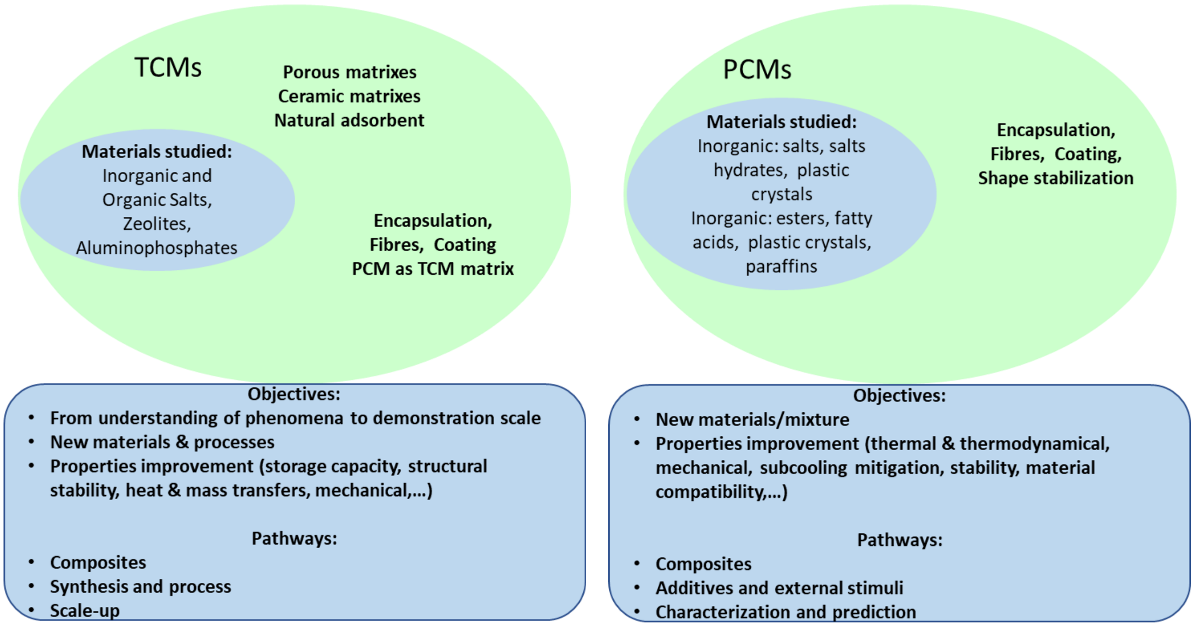

Figure 2-2: Overview of the materials studied in Subtask B.

Section 4 of the extended final report covers the materials studied, as well as the R&D objectives and pathways contributed by the participating experts and institutions.

2.3 Subtask C: State of Charge Determination

The objective of Subtask C was to collect, classify, and disseminate promising techniques with which the state of charge (SoC) of a CTES unit can be determined. Specific activities of Subtask C were to make an inventory of material properties and measurements techniques that can be related to the SoC, to develop methods to link the measured properties to a numerical model of the CTES and use the combination to determine the SoC, as well as to test these in stand-alone storages and possibly in storages integrated in a system.

Subtask C experts defined a *thermal battery* as a TES system with instantaneous SoC determination. Therefore, SoC is a component level property, and its determination utilizes measurement techniques of material bulk response. The following Figure 2-3 defines three distinct levels to the development of SoC determination techniques for PCM and TCM CTES.

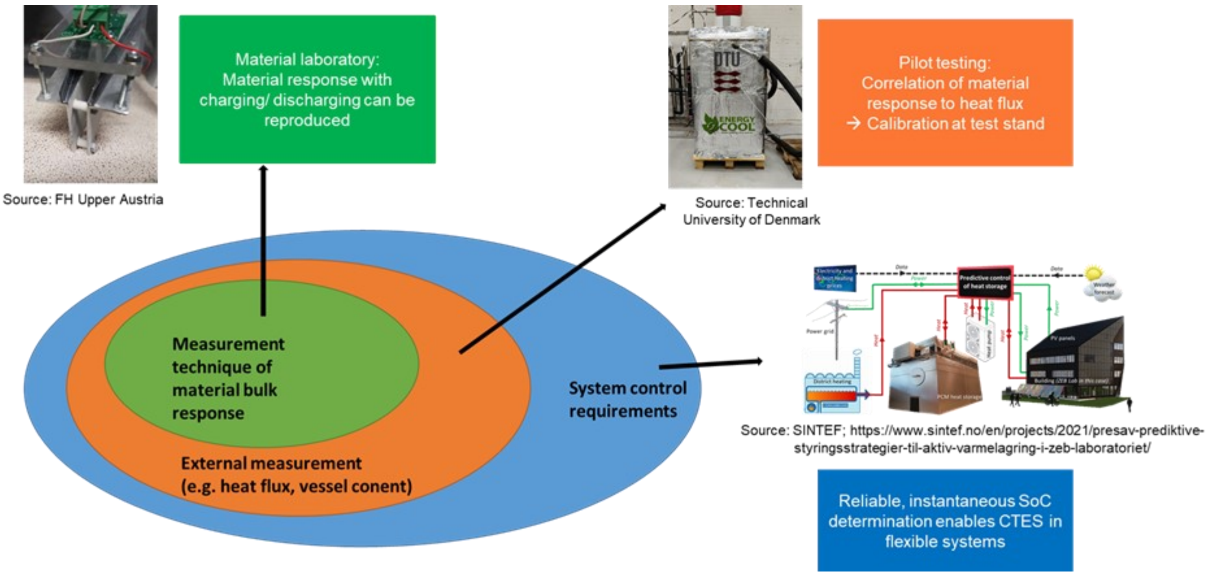

Figure 2-3. Schematic representation of the 3-level approach for the development of PCM and TCM SoC determination techniques linked to material properties.

The innermost level, *material level*, describes the development of measurement sensors and techniques able to provide data relating to an intrinsic material property of either the PCM/TCM or the external conditions imparting heat/mass to the PCM/TCM that are useful to determine SoC (typically TRL 1–3). The second level, *component level*, describes the development of the *material level* measurement techniques either internal or external to the PCM/TCM able to provide data that is calibrated to either bulk or local SoC determination (typically TRL 4–6). The third level, *system control*, describes the integration of the calibrated SoC determination techniques at the *component level* into a CTES system with electronic control (local or remote) at or near the final CTES configuration for end-use deployment (typically TRL 7–9).

To work towards the objective, Subtask C experts conducted three steps. First, an inventory of promising material properties and related measurement techniques. Regarding PCM, twenty technique submissions were collected. Eleven of them described techniques utilizing temperature measurements of the PCM medium and control volume boundary heat exchange. Regarding TCM, six main TCM SoC measurement techniques were submitted. Most, if not all these methods work at *material level* and used either in a laboratory experimental environment or at pilot scale. The two most promising methods to achieve higher TRL include (i) enthalpy balance SoC determination technique during system operation, and (ii) TCM mass or adsorbate mass balance SoC determination technique. As the second step, a collection of experimental and numerical proofs of concept were presented and explained in more detail. Third, descriptions of application requirements of four prototype systems, where a direct interaction of material bulk response with the control system is in place, were prepared.

2.4 Subtask D: Stability of PCM and TCM

In Subtask D, a better understanding of the stability of PCM and TCM during their lifetime and the development of recommendations for an application-oriented investigation of this stability were addressed. The goal was to support R&D on PCM and TCM with a predictable and improved stability.

Previous works and the state of literature lack differentiating degradation mechanisms, showing which test methods are suitable for determining the respective degradation, and making (material class-specific) recommendations for accelerating measurements.

In Task 40, a CTES material degradation table was proposed to map degradation mechanisms for CTES material classes, and to propose recommendations for stability testing based on simple experiments to faster investigate stability by accelerating degradation. The developed approach to map degradation of CTES materials provides a comprehensive overview of the degradation mechanisms and the corresponding degradation factors which are relevant for a specific material or material class. Such a mapping diagram informs (scheme shown in Figure 2-4) about the effect of different types of degradation on the CTES material and system.

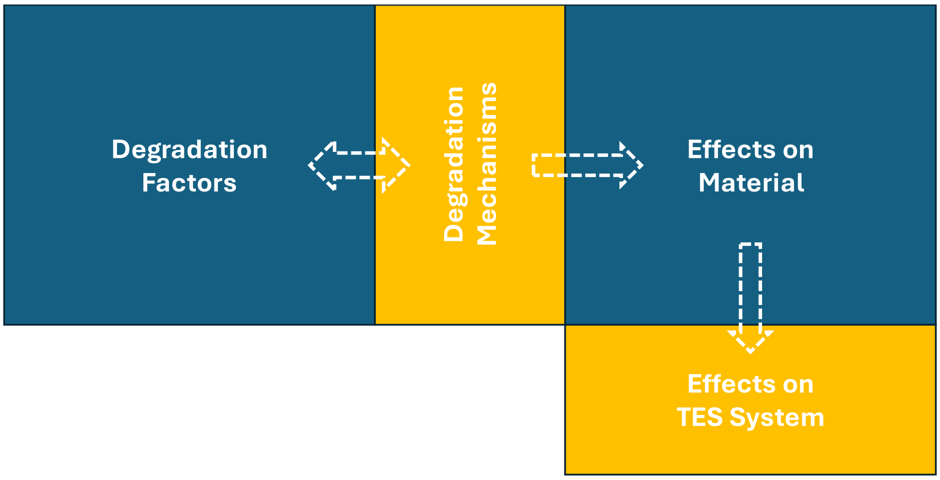

Figure 2-4. Scheme of the degradation mapping diagram to illustrate PCM and TCM stability.

Task experts provided their degradation expertise about the following CTES materials (classes): Organic plastic crystals, lauric and adipic acid, fatty esters, saturated triglycerides, calcium chloride hexahydrate, sodium acetate trihydrate, disodium hydrogen phosphate dodecahydrate, zeolites, potassium carbonate, and sulfates. Evaluating these eleven examples for CTES materials degradation mapping, it became evident that a certain effect on the material (e.g. a transition temperature displacement) can be caused by different degradation mechanisms. In the same way, effects on the storage system performance can usually be attributed to a combination of different effects on material level. In practice, stability tests under application conditions can only be carried out reasonably if there is an understanding of the dependencies between degradation factors, degradation mechanisms, and effects on the CTES material and system. Such an understanding can be summarized and communicated using the developed degradation mapping diagram.

2.5 Subtask E: Effective Component Performance with Innovative Materials

Subtask E focused on material-component interaction for an improved storage system performance. This was attained by defining performance parameters, understanding the mechanisms that determine the performance-based interaction between storage material and components, and identifying methods for improved component and material design. Work was split up between PCM and TCM experts, and the outcomes are presented separately.

2.5.1 PCM

Performance indicators for PCM components (mainly heat exchangers) were defined and agreed upon. These indicators allow a fair comparison of latent heat thermal energy storage units. This has not been possible so far. For example, a comparison of the average thermal power is strongly influenced by the initial and boundary conditions during the experiment. Three methods were developed by the Task participants to minimize these influences and enable a comparable analysis.

The idea behind the first method is to normalize the heat transfer rate $\dot{Q}$ by the volume and a reference temperature difference, calculate a mean value and present the results plotted over a normalized mean value of the capacity flow of the heat transfer fluid in a so-called $\overline{\dot{C}^{\mathrm{norm}}}/\overline{\dot{Q}^{\mathrm{norm}}}$-plot.

The second method, called *three sections approach*, helps finding a suitable stop criterion for calculating a mean value of the power of latent heat thermal energy storage units. Tangents are laid through the inflection points that occur in a characteristic discharge power curve of a latent heat thermal energy storage unit. The discharging process is divided into several sections and the end is determined based on their intersections with each other and with the zero line, respectively.

Depending on the operating conditions, the actual usable heat content of a thermal energy storage can deviate significantly from the theoretical storage capacity calculated from the geometry and material parameters. This can drastically reduce the amount of usable heat, especially at high thermal power rates. The third method is intended to take these dependencies into account. It is based on a small number of standardized charging and discharging measurements with a constant volume flow and constant inlet temperature. The resulting power curves are normalized and converted from the time domain to the energy domain. The curves are plotted in such a way that the actual usable heat content of the storage can be determined for specified values for the set thermal power, the temperature, and the maximum volume flow.

2.5.2 TCM

In the case of TCM components, there is a need for a standardized evaluation of sorption heat storage components and systems with respect to the material performance given by the vapor pressure versus temperature relationship of various concentrations or mass fractions. This standard evaluation will make it possible to quantify development success.

The developed performance mapping technique uses a concentration vs. gross temperature lift diagram, which incorporates the sorbent's equilibrium line and the deviation caused by the non-linear temperature-heat relationship. As shown in Figure 2-5, deviation from the equilibrium indicates performance loss. The performance map of the sorption heat storage is based on a good characterization of the sorption material used.

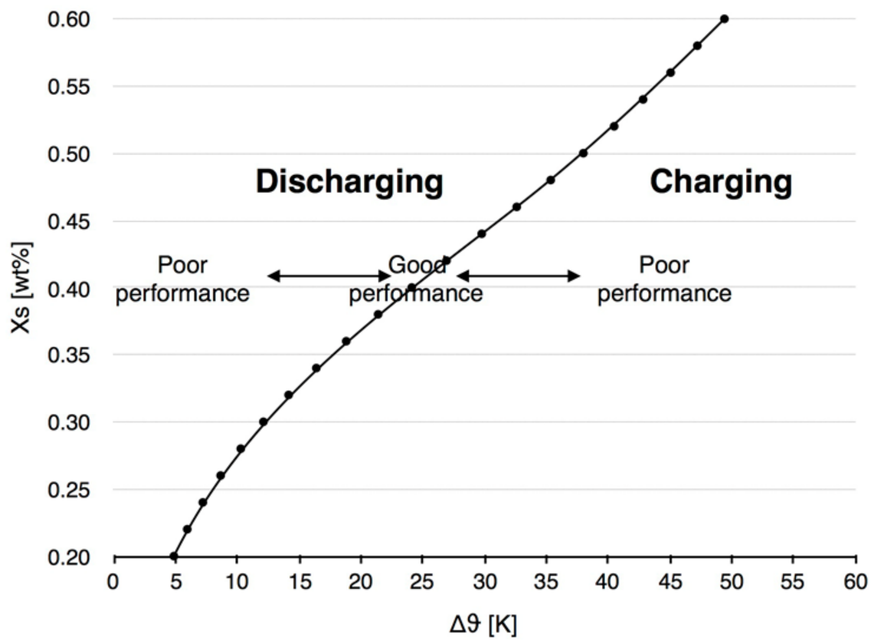

Figure 2-5. Illustration of the mapping procedure, where the x-axis represents the temperature difference between sorbate and sorbent and the y-axis represents the weight percent or mass fraction. Deviation from the theoretical curve indicates loss of system performance.

This mapping helps visualize the operational constraints and the potential performance of the system. There is a non-linear relationship between temperature gain and heat release in all sorption processes. As the sorbent's concentration increases, the temperature gain also increases, but the heat release rate does not linearly follow, leading to potential stagnation in heat transfer, particularly when high-temperature gradients are required. The work emphasizes the importance of operating the system at the minimum necessary temperature rise (gross temperature lift) to optimize heat transfer.

To overcome the problem of incomparable test results from different test methods, a uniform test guideline for building applications was proposed. The proposed guideline defines specific static test temperatures that correspond to realistic operating conditions:

- Desorption: Heat source temperatures are set to a maximum of 95 °C input and 92 °C output, which are conditions achievable by solar thermal systems without exceeding practical limits.
- Condensation: Heat rejection during charging is performed with water-based HTF at 30 °C inlet and 35 °C outlet, in line with standard heat pump conditions (EN 14511).
- Evaporation: Discharge evaporation takes place at 10 °C inlet and 7 °C outlet, simulating typical low temperature ground heat sources in building environments as defined by the EN 14511 heat pump test standard.
- Sorption: Heat absorption also follows the heat pump standard, with HTF temperatures of 30 °C inlet and 35 °C outlet.

This guideline standardizes the evaluation of sorption heat storage systems by ensuring that materials, components, and systems are tested under comparable and realistic conditions. By standardizing test conditions, the guideline facilitates more accurate comparisons of energy density power and temperature gain (gross temperature lift) performance, supporting the advancement of sorption heat storage systems as a viable solution for improving the energy efficiency of buildings.

3 Conclusions

Task 40 advanced the development of compact thermal energy storage by improving material characterization and development, establishing standardized testing methods, and enhancing the understanding of performance degradation. The international collaboration fostered innovation in both materials and components, laying the groundwork for more efficient and reliable CTES systems. These efforts will contribute to accelerating the market integration of CTES technologies and support the broader transition toward sustainable, renewable-based energy systems.

The Task achieved good success in enhancing material characterization skills through the development of measurement guidelines and in building a comprehensive knowledge base for state of charge determination techniques. The strong international collaboration within the CTES community was also supported. However, dissemination of lessons learned, broader utilization and expansion of the materials database, and development of guidelines for component design and evaluation fell below expectations. Going forward, two new Tasks will focus separately on TES materials and components to build on the progress made.