SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 67: Compact Thermal Energy Storage Materials within Components within Systems

Semi-Annual Status Report: 23 November 2022

92nd ExCo Meeting, 5+6 December, Stellenbosch, South Africa

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EXECUTIVE SUMMARY & ISSUES

Task Description

The purpose of the Task is to push forward the compact thermal energy storage (CTES) technology developments to accelerate the market introduction of these technologies through the international collaboration of experts from materials research, components development and system integration, and industry and research organizations.
The main objectives of the Task are to 1) better understand the factors that influence the storage density and the performance degradation of CTES materials, 2) characterize these materials in a reliable and reproducible manner, 3) develop methods to effectively determine the State of Charge of a CTES, and 3) increase the knowledge base on how to design optimized heat exchangers and reactors for CTES technologies.

Significant Developments & Results Since Last Report

- The round robin tests are running now. Preliminary results on the determination of material density were presented and discussed.
- A proposal was made on how to classify relevant material properties and how they influence CTES characteristics in order to apply this for material improvement learning curves.
- For the determination of the state-of-charge for sorption storages, methods applying inductive measurements were presented.
- A template was designed, with which the stability of CTES materials can be mapped. This template will be tested.
- With regard to the improvement of material-component interaction, two methods to simplify the comparison of heat exchanger performance for PCM were presented and will be developed further.

Participating Countries

Austria	SHC	Norway	SHC
Canada	SHC	Portugal	SHC
Denmark	SHC	Slovenia	ES
France	SHC	Spain	SHC/ES
Germany	ES	Switzerland	SHC
Italy	SHC	United Kingdom	SHC
Netherlands	SHC	United States	ES

Task Duration

1 October 2021 to 30 September 2024

Collaboration with other SHC Tasks, IEA Programmes, Outside Organizations/Institutions

Task67 is a fully joint Task with the IEA Energy Storage TCP Task40. Task Manager for the Task40 part is Andreas Hauer, ZAE Bayern, Germany

Issues for the ExCo

Issues for Participating ExCo Members

- none

Issues for Full ExCo

- The discussion on the continuation of relevant activities after the end of Task 40 was continued during the 3rd expert meeting. Overall, most meeting participants were positive to continue working on CTES material topics in the context of such an international group of experts. A specific proposal as to the framework and work plan in which this continuation could be organized is not yet in place.

TASK DESCRIPTION

Scope and Objective

CTES technologies are the subject of the Task. These technologies are based on the classes of phase change materials (PCM) and thermochemical materials (TCM). Materials from these classes will be studied, improved, characterized and tested in components. The main components for these technologies are heat exchangers and reactors and these are also studied and further improved in the Task. The temperatures of the heat that will be supplied by the thermal storage are determined by the areas of application and range from 0°C to 20°C for cooling purposes, from 40°C to 95°C for buildings, between 60°C and 130°C in DHC networks and 80°C to more than 500°C for industry and vehicles. Due to the underlying physical and chemical processes, the charging and discharging temperatures, especially with TCM, can have very different values, with charging temperatures mostly determined by the applied heat source.

The main objectives of the Task are to have a better understanding of the factors that influence the 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 SoC of a CTES and to have better knowledge on how to design optimized heat exchangers and reactors for CTES technologies.

To achieve these objectives, the work is organized into the following Subtasks
Subtask A: Material Characterization and Database
Subtask B: CTES Material Improvement
Subtask C: State of Charge – SoC Determination
Subtask D: Stability of PCM and TCM
Subtask E: Effective Component Performance with Innovative Materials

Subtasks and Lead Countries

Subtask A: Material Characterization and Database
Lead Country: Austria
Subtask Leader: Daniel Lager, AIT
Objective: To develop and validate several standardized measurement procedures for CTES materials and to further expand and maintain the materials database and knowledge database.

Subtask B: CTES Material Improvement
Lead Country: Spain
Subtask Leader: Stefania Doppiu, CICenergiGune
Objective: To identify proper strategies that allow for tuning the reactivity of CTES materials thus improving their properties and final performances.

Subtask C: State of Charge – SoC Determination
Lead Countries: Denmark (PCM) and Canada (TCM)
Subtask Leaders: Gerald Englmair, DTU and Reda Djebbar, CanMETenergy
Objective: To develop techniques with which the SoC of a CTES can be determined in a reliable and cost-efficient way.

Subtask D: Stability of PCM and TCM
Lead Country: Germany
Subtask Leader: Christoph Rathgeber, ZAE Bayern
Objective: To arrive at PCM and TCM with a predictable and improved stability.

Subtask E: Effective Component Performance with Innovative Materials
Lead Countries: Spain (PCM) and Switzerland (TCM)
Subtask leaders: Ana Lazaro, Univ. of Zaragoza; Andreas König-Haagen, Univ. of the Basque Country and Benjamin Fumey, Lucerne Univ. of Applied Sciences.
Objective: to improve material-component interaction for optimal system performance.

PROGRESS SINCE LAST EXCO MEETING

Within the reporting period, the 3rd expert meeting of Task 40 took place on 29–30 September 2022. The meeting was organized in connection with the EuroSun 2022 conference in Kassel, Germany. It was a purely physical meeting with 41 participants from 28 different institutions located in 12 different countries.

Figure 1: 3rd expert meeting of Task 40 in Kassel, Germany.

During the lively discussions, the work progress within the five Subtasks was presented and discussed. Several participants introduced their work related to CTES materials or provided updates on their CTES material R&D projects.

Subtask A - Material Characterization and Database

Subtask A deals with CTES material characterization. Standardized procedures to measure thermo-physical properties of PCM and TCM will be developed and tested via round robin tests. The existing database *www.thermalmaterials.org* for high-quality measurements of material properties will be maintained and expanded.

Overall, 39 institutions from 15 countries participate in four round robin test groups:

1. Thermal conductivity and thermal diffusivity of liquids, solids, and packed beds
2. Specific heat capacity of powdery materials
3. Enthalpy change due to sorption or chemical reaction
4. Thermal expansion, density, and viscosity determination

The Subtask A leader stated that the round robin test activities are running - with some of them already further along, some at the beginning. For each round robin test, the used measurement equipment, the material to be tested, the sample preparation routine, and the test procedure was presented by the Subtask A leader based on slides provided by the round robin test coordinators.

Preliminary measurement results were presented for the round robin test on density. Figure 2 shows the measured densities obtained by two round robin test participants.

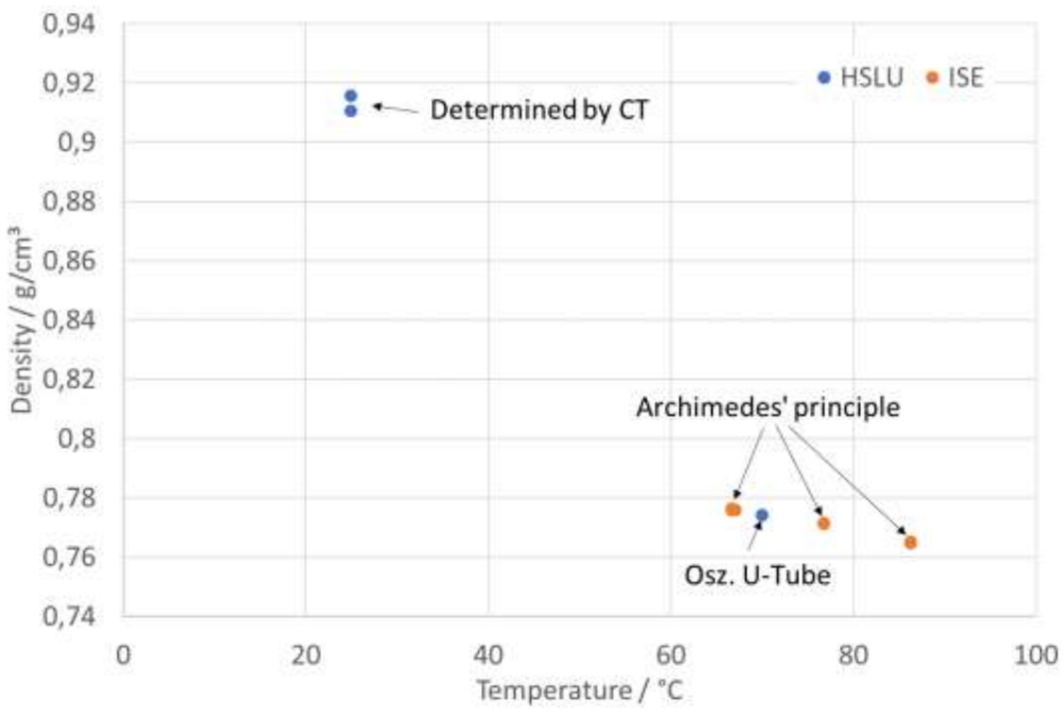

Figure 2: Preliminary results of the round robin test on density measurements.

As sample material, a paraffin with a melting temperature between 53 and 58 °C was used. So far, results from two contributors, HSLU and Fraunhofer ISE, can be compared. HSLU carried out computer tomography (CT) to measure the density in solid state. The liquid state was measured via oscillating U-Tube principle. Fraunhofer ISE performed measurements according to Archimedes principle to obtain the density in the liquid state. At AIT, density measurements with a dilatometer were not possible due to gas inclusions, formation of cavities while solidifying, and leakage during measurement. As soon as additional measured data from further institutions are available, the results will be compared to evaluate the density measurement procedures.
As one of the next steps, the material database *www.thermalmaterials.org* is to be tested, especially about the handling of the measurement data upload. In addition, the data content of the database will be extended by uploading measurement data from the group of participants. At the meeting in Kassel, the discussion on how to maintain and utilize the material database after Task 40 was continued. It was agreed that the database can be valuable part of dissemination of the Task results. A plan on how to organize the database maintenance including the website hosting is to be elaborated in the remaining Task period. To proceed, an intermediate online meeting will be organized by Stefan Gschwander, Fraunhofer ISE.

Subtask B - CTES Material Improvement

The objective of Subtask B is to identify proper R&D strategies that allow for tuning CTES materials, thereby improving their material properties and performance in storage components.
To achieve this objective, three topics will be addressed in detail:

1. “Exploring” potential materials (PCM/TCM)
2. Composites for improved performances (PCM and TCM)
3. Final guideline for materials improvements (KPIs), relationship production methods material performances, impact on system design.

The following Figure 3 outlines the scope of topics 1. and 2.

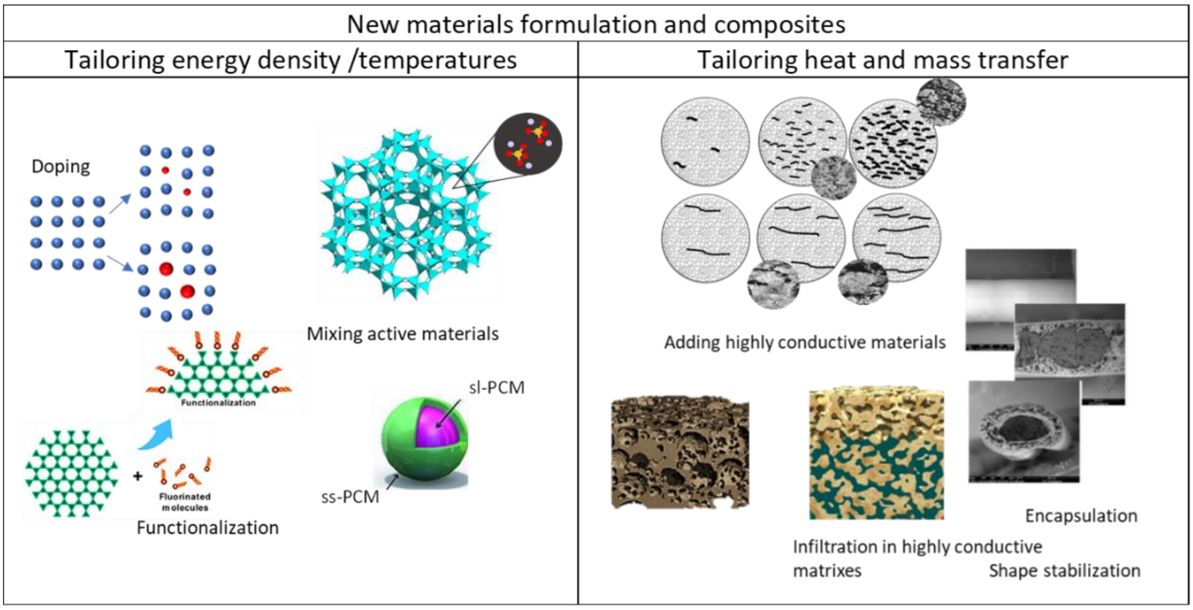

Figure 3: CTES material tuning approaches of Task 40 experts.

Several presentations from Task 40 participants followed the introduction of the Subtask leader.
The development of cycling stable TCM with high energy densities at TU Wien was presented by Peter Weinberger. He explained the basic material selection process as well as strategies to improve charging/discharging cycling stability by preparing composites of salts and carrier materials, e.g. zeolites.
Rebecca Ravotti of HSLU presented their PCM material research activities, covering among others the topics synthesis of esters as PCM, investigation of polymorphic crystallization, and computer tomography as a versatile material characterization technique.
Material research on plastic crystals as solid-solid PCM was one of the topics presented by Angel Serrano of CIC EnergiGune. Considerable solid-solid transition enthalpies and the inherent shape stability are among the advantages of plastic crystals in the context of PCM.
Inés Fernández of University of Barcelona presented their work on the use of nanoparticles to enhance the behavior of heat transfer fluids and PCM. Focus of investigation was if the addition of nanoparticles in small amounts can increase the specific heat capacity significantly. Overall, the conclusions were drawn that the specific heat increase is comparably low, that it is doubtful if the heat transfer fluid/PCM + nanoparticle mixtures will be stable over the period of use, and that the high cost of nanoparticles is still an obstacle to their applications.
In the context of tailoring energy density/temperatures, Christoph Rathgeber of ZAE Bayern presented their approach to develop PCM based on salt hydrate mixtures. The approach consists in calculating solid-liquid phase diagrams of mixtures of salt hydrates and salts, and a subsequent experimental verification of predicted eutectic mixture composition.
To assess material improvement strategies and to link improvement on material level to the behavior of CTES materials in components, the following table (Figure 4) was presented and discussed.

CTES characteristic	Property on material level (*PROP*)	KPIs on component level (*KPI*)	Direction of optimization
Amount of energy stored per mass or volume	• Melting enthalpy of PCM (per mass or volume) • Max. reaction enthalpy of TCM (per mass or volume) • Cp	• Storage capacity (per mass or volume)	Towards *PROP* (*KPI* always less than *PROP*)
Energy uptake and release rate	• Thermal conductivity • Thermal conductivity normalized by ? • Mass transfer • Kinetics?	• Power (normalized) during charging/discharging	To be increased towards application requirements
Stability	• Change of material properties with – number of charging/discharging cycles – (testing) time	• Change of storage capacity or power with – number of charging/discharging cycles – (operation) time	Towards "no change"
Costs	• Costs per mass or volume of CTES material • Costs per specific enthalpy change	• Costs per 1 kWh of capacity • Costs per 1 kW of power	To be decreased towards application requirements

Figure 4: CTES material characteristics with related properties on material level and related KPIs on component level.

This schematic shows the difference between properties on material level and Key Performance Indicators (KPIs) on component level, as well as the target of optimization of material properties for the relevant CTES characteristics *energy*, *power*, *stability*, and *costs*. It was also discussed if and how such a classification can be applied to prepare material improvement learning curves showing the evolution of research over the past years and Tasks.

Subtask C - State of Charge – SoC Determination

In Subtask C, techniques with which the SoC of a CTES can be determined in a reliable and cost-efficient way are to be identified and/or developed. SoC determination, as the connection between material research and thermal energy storage system integration, is an important prerequisite for integration of CTES into any (digitalized) future energy system. For this purpose, two activities are running. First, to work on an inventory of promising material properties and related measurement techniques. The inventory will be based on a collection of methods for PCM and TCM thermal energy storage units, which have been developed by the participating organization or which have been published in literature. Second, to work on a collection of experimental and numerical proof of concepts including tested measurement techniques and sensor technologies.
To discuss and sort the collected SoC determination examples, a three-level schematic was developed and further refined during the 3rd expert meeting (Figure 5). Measurements on material level (green circle) are usually calibrated with external measurements on component level (orange circle). System control requirements are application specific and define, for example, the necessary SoC determination uncertainty, SoC determination frequency, and the communication between SoC measurement (device) and storage system integration.

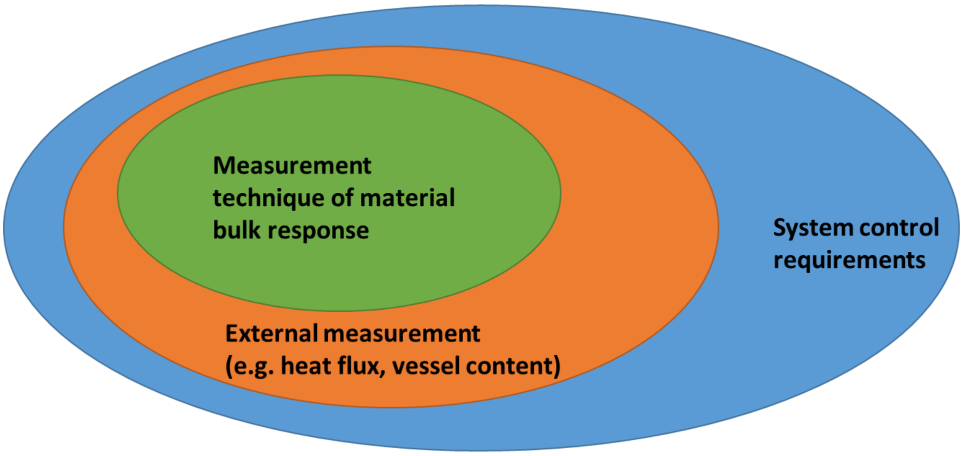

Figure 5: Three levels to discuss state of charge determination methods.

In this context, the term *bulk* refers to a sample size that is sufficiently large to be representative for the CTES material behavior at application scale.
Following the introduction, the Subtask C leader presented examples for the two running activities provided by Task experts.
As next steps, another Subtask C online meeting is planned for January 2023. There, the focus will be on the third Subtask C activity "Description of application requirements" dealing with system control requirements. It was recommended by the Task experts to consider previous Task work, e.g. the final report of Task 30.

Subtask D - Stability of PCM and TCM

A better understanding of the stability of PCM and TCM during their service lifetime and recommendations for an application-oriented investigation of this stability are addressed in Subtask D.
Four activities are planned within Subtask D:

1. Establish a definition for PCM and TCM stability
2. List the relevant degradation mechanisms for different material classes
3. Discuss how degradation can be accelerated to faster investigate stability
4. Develop recommendations for stability testing based on simple experiments

It was decided to deal with activities 2 to 4 first and – based on their results – to come back to working on a definition for PCM and TCM stability.
To proceed with activity 2, the Subtask D leader presented a template (Figure 6) to map the stability of different CTES materials or material classes.

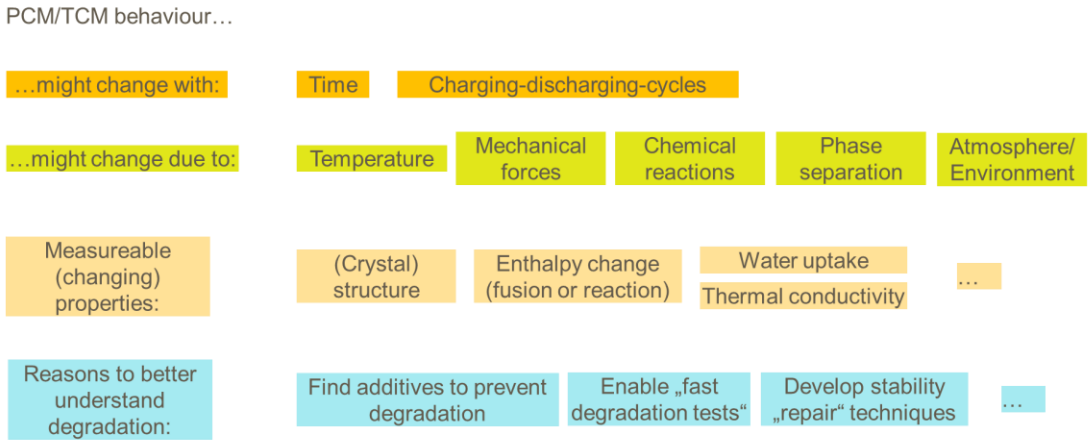

Figure 6: Template for CTES material stability mapping.

As an example, the application of this template to salt hydrates (to be used as PCM) is shown in Figure 7.

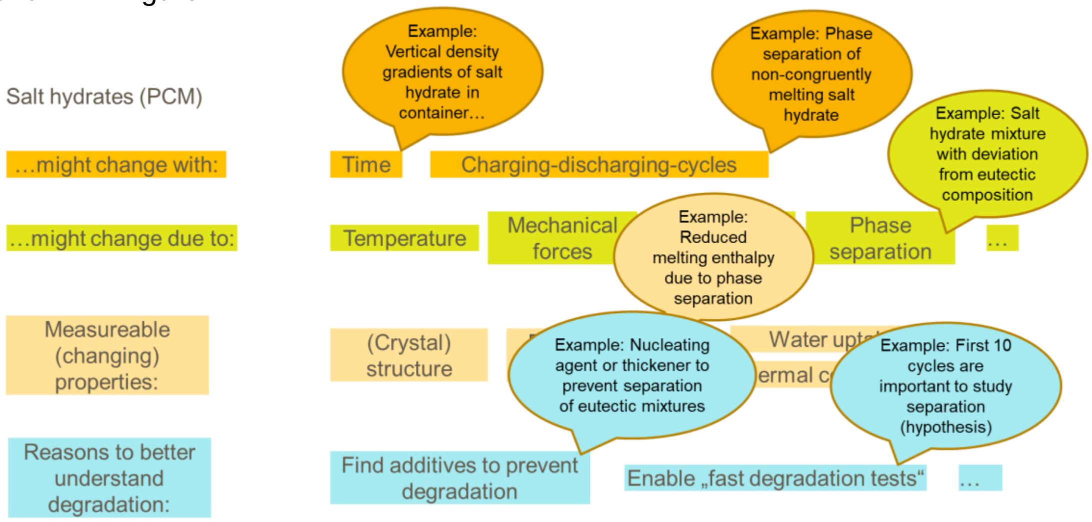

Figure 7: Salt hydrates (PCM) stability mapping.

The template is to be discussed, tested, and refined based on the feedback of Task experts. During the 3rd expert meeting, participants already recommended to add the following:

- Develop “stability repair” techniques (e.g. mixing of liquid samples to counteract phase separation of different mixture components)
- Influence of atmosphere/environment on CTES material stability

The next steps in Subtask D are updating the contributor table and completing further CTES material stability mapping templates for CTES materials or material classes which are under investigation by the Task experts.

Subtask E - Effective Component Performance with Innovative Materials

The goal of Subtask E is to improve material-component interaction for optimal system performance. This is attained by defining performance parameters, by studying the mechanisms that determine the performance-based interaction between storage material and components (e.g. heat exchanger or heat and mass exchanger), and by locating and applying methods for improved component and material design.

To define TES performance parameters, several approaches were already discussed at the previous expert meetings. At the 3rd expert meeting, an update of the approach of ZAE Bayern to evaluate charging/discharging power curves of PCM thermal energy storage units was presented. This method calculates charging/discharging curves with constant power output based on constant volume flow experiments. The underlying motivation are the two questions: “How long can the PCM storage deliver a constant power? How much energy can be delivered at constant power until power drops under a certain threshold value?” Based on two experimentally examined PCM storage units, the energy charged/discharged in constant volume flow experiments is equal or less than the energy charged/discharged at constant power operation. Thus, considering the usable energy content determined in constant volume flow experiments might serve as a rough and conservative estimation for the usable energy content at constant power operation. This conclusion is to be backed up with more experimental results.

Andreas König-Haagen from the University of the Basque Country presented an *UA* approach for predicting the discharging time of latent heat storage units. This approach predicts the discharging time of a latent heat storage with plate heat exchangers with air or water as heat transfer fluid. In a parameter study, the heat transfer coefficient, the PCM properties, and the heat transfer fluid mass flow were varied. Results are compared with a validated numerical model. Figure 8 shows this comparison for a Stefan number of 0.02, air as heat transfer medium, a heat transfer coefficient of 1000 W/(m² K), and two different thermal conductivities of the PCM (0.1 and 2 W/(m K)).

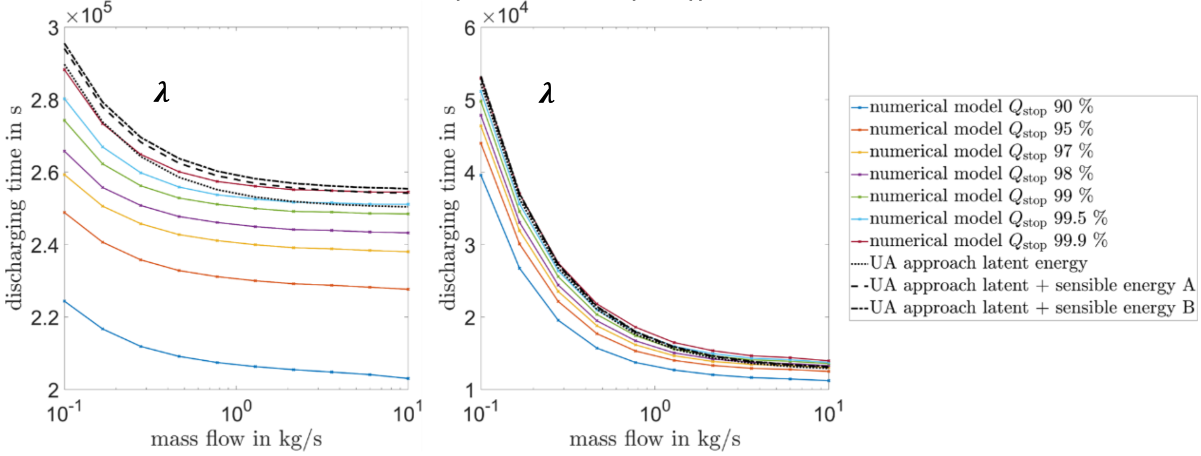

Figure 8: Comparison of UA approach and numerical model to evaluate the discharging of latent heat storage units.

A satisfying agreement between the *UA* approach and the numerical model is observed for the higher thermal conductivity (2 W/(m K)) and a stopping criteria for the discharged energy of more than 99%. Further results of this parameter study were presented and discussed. At the next experts meeting or during an intermediate Subtask E online meeting, this discussion can be continued.

DISSEMINATION ACTIVITIES

This is a record of **all** publications and conferences/workshops. The publication section will be fully updated in the next report.

Reports, Published Books & Online Tools

Author(s) / Editor	Title	Report No. AND Publication Date (month, year)	Target Audience	Web or Print AND "RE" if restricted access*

* RE = restricted so available only to Task participants via internal Task website

Journal Articles, Conference Papers, Press Releases, etc.

Author(s) / Editor	Title	Publication / Conference (name of journal, newsletter, conference, etc.)	Bibliographic Reference (journal number, year, place, editor, etc.)

Conferences, Workshops, Seminars

Conference / Workshop / Seminar Name	Activity & Presenter (keynote, presentation, poster, etc.)	Date & Location	# of Attendees	If Task Hosted: # Countries, Industry, Government, Research
ISEC 2022	Poster, Wim van Helden	6-7 April 2022	~ 350	

TASK MANAGEMENT

Participating Countries and Sponsors

Country/Sponsor	National Participation Letter (Y/N)	Number of Research Institutes	Number of Universities	Number of Companies
Austria	Y	2	4	
Canada	N	1	3	
Denmark	N		2	
France	N	1	6	
Germany	ES TCP	3	6	1
Italy	N	2	1	
Netherlands	N	1	1	
Norway	N	1		
Portugal	N	1	1	1
Slovenia	ES TCP	1		
Spain	N	2	4	
Switzerland	N	1	1	
United Kingdom	N		5	1
United States	ES TCP	2	1	
Total: 17		18	38	4

Past and Future Expert Meetings (including Task workshops, etc. held in conjunction)

Meeting #	Date	Location	Number of Participants & Countries/Sponsors
1	27-29 Oct 2021	Vitoria Gasteiz, Spain	24 (in person), 35 (virtual) 15 countries
2	4-5 April 2022	Graz, Austria	38 (in person), 13 countries
3	29-30 Sep 2022	Kassel, Germany	41 (in person), 12 countries
4	24-26 April 2023	Halifax, Canada	
5			
6			
7			

Deliverables

Subtask A: Material Characterization and Database

No.	Deliverable	Month
DA1	Standardized measurement procedures and round robin tests	36
DA2	CTES Materials database and knowledge platform	36

Subtask B: CTES Material Improvement

No.	Deliverable	Month
DC1	Novel tailor-made and improved CTES materials and composites to actively enhance performances	36
DC2	Production methods and final materials performances	36

	relationships	

Subtask C: State of Charge – SoC Determination

No.	Deliverable	Month
DC1	Description of techniques to determine the SoC of PCM and TCM thermal storages	36

Subtask D: Stability of PCM and TCM

No.	Deliverable	Month
DD1	Description of PCM and TCM degradation mechanisms	18
DD2	Recommendations for stability testing of PCM and TCM	30

Subtask E: Effective Component Performance With Innovative Materials

No.	Deliverable	Month
DE1	Document on material – component interaction performance indicators	18
DE2	Realistic application specific performance chart definition	36

APPENDICES

Appendix 1. TASK EXPERTS

The listed experts participated in at least one of the three expert meetings.

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