Publishable summary

Project title: SolChemStore, Efficient System to enable storage of high temperature solar heat energy

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Project Website: www.solchemstore.eu

Executive Summary

The goal of this research project was to develop a thermo-chemical heat storage technology for high temperature and high density heat storage working on the basis of a reversible gas-liquid ab- and desorption process. Combined with solar thermal plants it enables a save and stable usage of fluctuating solar energy for high temperature industrial processes or can store high temperature waste heat to be reused. The envisaged technology will then be capable to save primary energy and reducing energy costs in heat consuming industrial processes or power plants. To realize this technology 4 European SMEs, 1 large enterprise and 2 research institutes from 4 European countries formed the consortium of the Research for the Benefit of SMEs project SolChemStore funded by the European Commission within the 7th framework programme.

GENERAL PROJECT APPROACH
The project started with an intensive scientific/technological characterization and a laboratory test phase. Storage materials pairs were characterized, the thermodynamics were described, novel continuous reactor concepts were developed and manufactured and the laboratory test system was designed built and commissioned.
A second phase followed where extensive experiments with the system and the chosen storage material pair were performed. The results of the experiments were very promising and showed that the very good values in terms of storage density and process behavior could also be achieved with industrial-scaled systems. The knowledge and results achieved were used to up-scale the laboratory test system by the factor of 3 and design a system in an industrial scale. The design includes the definition of the size of the main components and the definition of the sensor and control system.
The up-scaled laboratory test system was used to further develop and optimize the thermo-chemical heat storage technology based on the principle of gas-liquid ab- and desorption in a continuous mode of operation and to test further optimized reactor systems also beyond the project duration.
The SolChemStore project has successfully achieved a number of valuable scientific and technological
results in the field of storage material parameterization, process control as well as optimized design principles and manufacturing methods for continuous sorption reactors in terms of an efficient heat in-/output and mixing (kinetic) leading to the optimization the overall process design. Additionally important security aspects

concerning different used storage mediums could be worked out. According to the gathered information about the process and the behavior of such a continuous absorptive heat storage system important knowledge was elaborated. On the basis of this information it was possible to design a solar system in combination with an industrial scaled heat storage system for two different industrial sites. The system can also be designed for a CHP plant or an industrial waste heat source and the corresponding heat consumer (i.e. food industry).

Summary description of the project context and the main objectives

SCOPE OF THE SOLCHEMSTORE PROJECT AND OBJECTIVES
In industry a huge amount of heat energy is needed in various processes. Especially for heat intensive industry sectors like for example the food industry heat is very valuable as it is used for pasteurization, blanching and sterilization. Great advantages arise if this heat can be reliably provided by solar thermal systems or if waste heat can be stored and reused at the needed temperatures of these industrial processes. For many applications, especially for higher temperatures above 100°C there are no systems on the market that can fulfill these demands. With the SolChemStore project the project partners want to fill this gap. The goal of this research project was to develop a heat storage technology for lossless high temperature and high density heat storage. Combined with solar thermal plants it enables a save and stable usage of fluctuating solar energy for high temperature industrial processes or can store high temperature waste heat to be reused. The envisaged technology will then be capable to save primary energy and reducing energy costs in heat consuming industrial processes or power plants.
The main objective of the SolChemStore project was the development of a new method of thermo-chemical heat storage. This was done by using novel materials for a newly developed reactor that enables the application of a thermochemical process involving reaction pairs to provide heat storage. A system has been developed and will further be optimized that will be appropriate for use in industrial applications where heat between 100 to 200°C is required. The concept for the overall system includes a reactor, storage vessels and process control equipment, which has been designed in a format as simple as possible to ensure that it can be easily installed and maintained at the site where heat is needed.

With over 310,000 companies involved in the food and drink sector in Europe, 99.1% of these being SMEs, this sector has been selected as the primary target market. Energy use in this sector is high due to processes requiring steam or hot water such as cooking, evaporation, sterilisation, drying, space heating and baking. However, other sectors such as abattoirs, the pharmaceutical industry, paper and pulping and the chemical industry could also see significant reductions in process costs due to a lower use of fossil fuels associated with the SolChemStore technology.

WHY THERMO-CHEMICAL HEAT STORAGE?
Due to the physical principle of thermo-chemical heat storage the technology has potentially important advantages compared to state of the art systems. Currently available industrially manufactured thermal storage systems regularly only store sensible heat. They usually use water as a storage medium thus restraining the storage density and limiting the storage temperature level to 100 °C at the most. Latent-heat storage units which may achieve slightly better storage density values regularly lack the required flexibility due to their defined operating temperature. The

disadvantage of both systems is their permanent heat loss due to the temperature difference between the medium and its environment. Insulation can reduce this effect, but only to a limited extent.

Thermo-chemical heat storage systems are relatively new, promising technology approaches with considerable benefits compared to both the sensible and the latent-heat storage systems. Here storage densities can theoretically be several times above those of the medium water; i.e. these systems can store much more energy without requiring a bigger construction volume. This energy is bound by means of physicochemical processes thus almost eliminating thermal loss. The combination of both advantages facilitates the efficient time-based storage of thermal energy and its transport

HOW DOES IT WORK?

Charging the storage system with solar- or waste heat means evaporating water molecules, desorbing them from the solution by an evaporation process with the heat to be stored. The system is fully charged when the solution reaches the equilibrium state according the prevailing pressure and temperature, which can be adjusted according to the intended application.

Heat storage is lossless as long as concentrated solution and water are separated.

Discharging works the other way around: The heat can be extracted by adding water vapor to the stored solution. The water vapor absorbs in the solution thereby diluting the solution in a strong exothermal process.

PROJECT PROGRESS

In the first half of the project a detailed study of the scientific background of heat storage with chemical reactions and absorption systems was performed. To enable a deeper understanding of the technology the physical and theoretical background of thermo-chemical heat storages was elaborated.

After an extensive literature research on possible material pairs followed by an investigation of the possible candidates in a reaction calorimeter (RC). By additionally applying economic criteria, NaOH was chosen to be used as material pair as reference for the SolChemStore technology. The heat storage process was modeled on the basis of the elaborated thermo-dynamical equations and the use of the selected material pairs. These model calculations formed the basis for dimensioning the storage reactor and the process design of the laboratory test system.

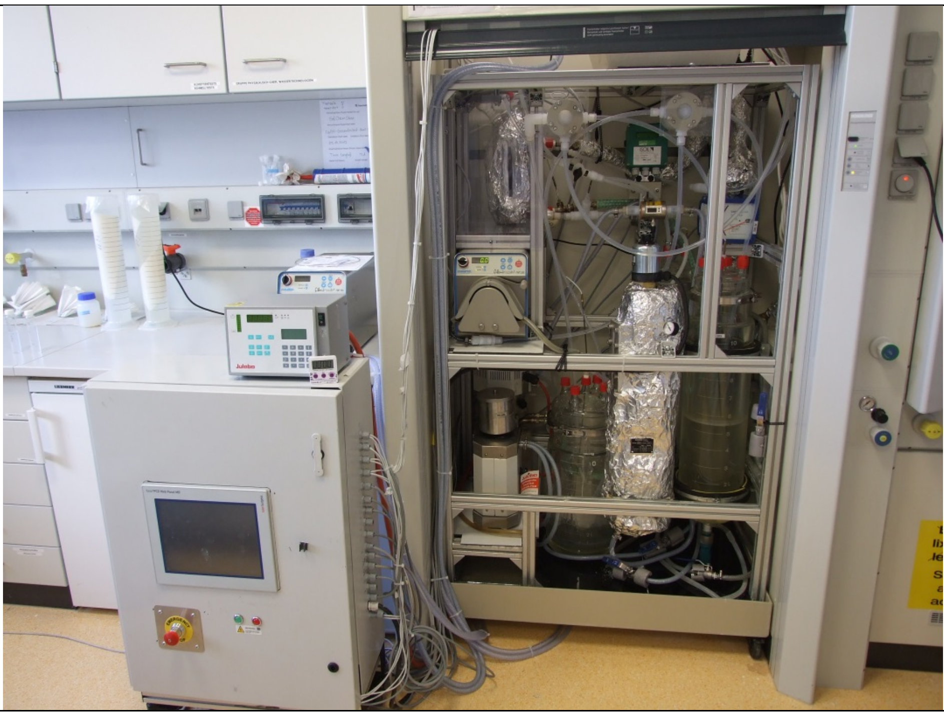
On the basis of information gathered regarding the requirements to the reactor, the material for the reactor was chosen to be high quality quartz glass. Flow simulations for different reactor designs and concepts were performed to identify the most suitable design for the shape was chosen and the necessary heat exchange area was dimensioned.

With the elaborated thermo-dynamical formulas for a continuous closed thermo-chemical reactor system the size of the subsystems (heaters/coolers, pumps, storages) could be dimensioned.

In a next step the necessary parameters that have to be measured to achieve a thermodynamic characterization involving a complete mass and energy of the system were elaborated. According to these measured parameters the necessary measurement and control devices for the system were defined and purchased.

A control system has been designed and manufactured. It features the possibility to control and update the control system from local and remote operators.

In the second half of the project the laboratory system was set up and the sensors were connected to the control system. The system was commissioned using liquid water as working fluid thereby determining the heat transfer value of the reactor. During the first test runs measures for improvement and optimization of the whole system were identified and implemented. An experimental plan for the charging and discharging cycles was worked out and run through with NaOH-solution as storage material pair. These cycles were performed at different temperatures of the simulated heat source/sink and different volume flows through the reactor leading to important conclusions concerning the heat in- and output, the charge and discharge power, the heat transfer and the efficiency of the whole process.
The results were summarized and analyzed and a theoretical re-evaluation of the system with regard to the up-scale of the system was performed, necessary changes in the system were defined and the system was successfully up-scaled.
After the successful up-scale of the laboratory test system an experimental plan involving charging and discharging cycles on the basis of the available heat sources and heat sinks at the solar cooling test system from Industrial Solar was elaborated. These cycles were performed according to the experimental plan and the behavior of the system was analyzed. The experiments were evaluated and interpreted by comparing the results with the simulated data. These results allowed very important conclusions concerning optimizations and improved reactor concepts. Following the process was theoretically considered at operating conditions which were not able to be investigated with the existing laboratory test system.
In this direction comprehensive work was done by performing several case studies which resulted in novel concepts for the up-scaled system, the reactor system as well as for future reactor systems and industrial scaled systems. After the proper operation of the system was proved a demonstration event was performed at the final project meeting at the Fraunhofer IGB laboratories. Thereby the project partners could observe the operation of the system.
A theoretical design of a system in an industrial scale was done. On the basis of two possible integration sites of two members of the project consortium (Picuezo, Industrial Solar) case studies for every site were performed and a theoretical system for the solar cooling test system from Industrial Solar in Freiburg was designed. The design includes the definition of the size of the main components and the definition of the sensor and control system including approximated prices for each component.



Up-scaled absorptive heat storage test system at Fraunhofer laboratories, Stuttgart

Description of the main S & T results/foregrounds

The SolChemStore project has successfully achieved a number of valuable scientific and technological results. The initial literature and laboratory work enables a deeper understanding of the storage material characteristics, the thermo-dynamics and the physical background of the heat storage principle with regard to a real technological application. The limiting factors and the main challenges were identified and technical measures to overcome these were taken. Innovative new concepts were developed. The thematic priority of this work was in the field of the storage material parameterisation, the process control, optimized design principles and manufacturing methods for continuous sorption reactors and the optimization of the overall process design.

Within the project material data of suitable heat storage materials was gathered by experiments and evaluation of literature.

The control system and algorithms are especially developed for thermo-chemical heat storage systems based on a reversible, continuous ab- and desorption. Various ways of process control are tested to be able to adopt the heat storage behavior to the needed characteristics of the used heat sources and heat consumers.

A new, innovative continuous sorption reactor was designed, built and successfully tested. For the manufacturing of this sorption reactor by the project partner Sico new Manufacturing Methods for Silicon reactors and heat exchangers have been applied and are further developed. Furthermore optimized concepts for sorption reactors including measures to enhance the mixing of the storage material and to optimize the heat transfer were developed.

As part of the process development the overall design of a continuous thermo-chemical absorption heat storage system was developed and will be continuously further improved. A central innovation is the modularity and scalability of the system which allows the system to be easily adopted to the needed performance (Storage capacity, heat power in-/output).

Until now, no thermo-chemical heat storage systems are on the market yet and the number of research activities is low. Furthermore in none of these activities a continuous system with this high modularity is developed or such high temperatures targeted. This represents a significant step forward compared to the state of the art.
Further concepts for simplifying and economizing the complete system by reducing the number of expensive system components like pumps and valves were also developed.

Description of the potential impact

An important contribution to the achievement of climate protection targets is an improved utilization ratio for both fossil and regenerative primary energy sources. This is done by secondary usage of energy which was not used during its first application. A case in point is the utilization of waste heat created by combustion engines during the generation of power from in CHP plants. In addition, there are many more processes in commerce, energy supply and manufacturing industry which generate large amounts of waste heat. Against the backdrop that about 50% of the EU energy requirements are needed for heat production it becomes apparent that there is great potential for optimizing energy use.

To optimize energy efficiency of processes, as well as to promote the necessary change to renewable energy sources by enabling a reliable supply of solar energy there is a need for compact and flexible storage systems to decouple or compensate the supply and demand for heat in terms of location through mobility and with regard to time through minimization of heat loss. Currently available industrially manufactured thermal storage systems regularly only store sensible heat. They usually use water as a storage medium thus restraining the storage density and limiting the storage temperature level to 100 °C at the most. Latent-heat storage units which may achieve slightly better storage density values regularly lack the required flexibility due to their defined operating temperature. The disadvantage of both systems is their permanent heat loss based on the fact that the driving gradient in both systems is the temperature difference between the medium and its environment. Insulation can reduce this effect, but only to a limited extent.
Within the project it has been experienced that the SolChemStore technology has a high potential to be used for efficient heat storage for various applications. Here storage densities can theoretically be multiple (up to 10 times) above those of the medium water; i.e. these systems can store much more energy without requiring a bigger construction volume. Temperature levels for charging and discharging are more flexible. The energy is bound by means of physicochemical processes thus almost eliminating thermal loss over the time. The combination of these advantages facilitates the efficient time-based storage of thermal energy and its transport. Numerous customers of the SolChemStore SME partners expressed their interest to enable the re-usage of waste heat, balance fluctuating energy demands or increase the efficiency of industrial processes.

With the heat storage technology energy and costs can be saved. The necessity of new heat storage concepts and technologies as an elementary part of a future energy supply becomes especially obvious with regard to the before mentioned fact that about half of the energy consumed in the EU is used as heat. It is obvious that efficient heat energy storage technologies will contribute to the international efforts to reduce the use of fossil fuels as well as intensify energy efficiency and the usage of renewable energy sources. It is the aim of the SolChemStore consortium that the newly developed technology will become an important element in this market in the future.

In parallel to the technical work dissemination activities took place at conferences and fairs and the involved SMEs had meetings with companies that are interested in the SolChemStore heat storage system to be used in their specific applications. Workshops and presentations show that such systems are needed for re-usage of waste heat, balance fluctuating energy demands and increase the efficiency of industrial processes. In the following months the up-scaled SolChemStore system will be further optimized regarding the requirements of of the envisaged applications.
Further activities regarding a follow-up projects are planned.

Project website: www.solchemstore.eu

Contact data coordinator

SICO Technology GmbH

Walter Nadrag

office@sico.at

Phone: +43(0)4244 5151 - 0