[HEAT SAVER]

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www.heat-saver.eu

Demonstration of a novel thermo-chemical heat storage system to improve energy-efficiency in CHP power plants and in solar driven industrial applications with high relevance in SMEs (HS-DEMO)

EXECUTIVE SUMMARY

The overall objective of the HS-Demo project as a follow up project to the successfully completed former EU - research project HeatSaver (Grant Agreement Number: 222116) was to realize the adsorption heat storage technology in practical applications like combined heat and power systems, solar thermal energy sources and others. This technology should help to save energy by allowing otherwise wasted heat to be stored and used at another time and if necessary place. The storage principle has significant advantages compared to other technologies in terms of heat storage density, flexible temperature levels and avoiding losses at long storage periods.

Within the first phase (Project HeatSaver) the proof of principle for the technology was successfully done. During the HeatSaver project, completed in 2011, a storage system with 0.75 m³ volume has been developed and tested to receive valuable data on the technical viability of a closed adsorption thermal energy storage technology. At the end of the HeatSaver project the proof of functionality has been performed. Different tests done under varying conditions showed a good performance. This further indicates the high potential of the technology. In total the project HeatSaver was successful and has delivered valuable results. To realize the adsorption heat storage technology as a closed system in practical applications and to take the next step towards the market, the consortium was able to start a new demonstration project. In November 2012 the HS-Demo project started with the objective to demonstrate the former developed technology for longer periods in industrial applications. Within the HS-Demo project it was planned to build, test and run two demonstration units to store thermal energy at different test sites.

To realize this, 4 European SMEs and 1 research institutes from 3 European countries formed the consortium of the demonstration project HS-Demo funded by the European Commission.

GENERAL PROJECT APPROACH

The project started with an intensive re-evaluation of the existing knowledge, a detailed review and analysis of the system developed within the HeatSaver project including the definition of measures that should be taken to improve the system design. The focus thereby was on the improvement of the system performance and on the facilitation of the industrial manufacturability of the system. The existing test unit from the former HeatSaver project was renewed and improved by the defined measures in preparation for the demonstration activities. After the technical adaptation of the system, numerous dynamic charging and discharging test runs were carried out, where the system showed a significantly improved performance regarding temperature peak, heat storage density, heat power as well as the rate of charging and discharging processes. This system represents Demo-Unit-I.

Based on a technically and economically optimized design the second demonstration unit (Demo-Unit-II) was built completely new. The design was jointly made by the project partners, with every partner having the focus on his expertise. An important point in the improved design of Demo-Unit-II was the definition and implementation of several approaches to achieve a standardization of the major parts of the demo unit. In the course of this standardization a list of the key components required to build the system have been done leading to a significant cost reduction in comparison to the former HeatSaver system.

To assess the suitability of a closed adsorption heat storage technology for different specific applications and to identify a number of potential end-users an extensive site survey has been performed including the set up and sending of a questionnaire to different new potential end users and other interested parties. The gained data helped to understand the end-user requirements and boundary conditions for the system and also showed the potential of the HeatSaver technology. Thereby three most suitable sites have been selected.

The installation of the storage Demo-Unit-I has been done at two different demo sites in order to demonstrate the system for a longer period of time. First it was installed and tested at demo site I where the stored heat was used for the purpose of the building space heating. Afterwards it was installed and tested at demo site II where it serves as a compact and reliable part of the energy supply of a demonstration house. The main heat sources available for charging purpose at the second demo-site are solar thermal collectors. At demo site III, where the Demo-Unit-II is installed and tested, the main heat source is waste heat from a saw dust burner. The stored heat has been used for heating the hot water cycle that is used for production of domestic hot water as well as building heating purposes. During the tests and demonstration activities different important parameters were measured and monitored. With the collected data, a detailed analysis was carried out which confirmed the expected system performance.

Until now, no thermo-chemical heat storage systems are on the market yet although the number of research activities is increasing. Furthermore in none of these activities a closed thermo-chemical sorption system in this size and on this economic and technological level has been developed yet. This represents a significant step forward compared to the state of the art and other similar research activities.

Further concepts for simplifying and economizing the complete system by reducing the number of expensive system components like pumps, valves and sensors will follow.

SCOPE OF THE HS-DEMO PROJECT AND OBJECTIVES

The EU Energy Efficiency Action Plan has highlighted the importance of energy efficiency in all economic sectors. Approximately 50% of Europe's energy demand is for heating purposes and anything that can reduce the amount of fossil fuel burned can only be for the good. In an age of spiraling demand for fossil fuels, with its associated environmental and geo-political ramifications, innovative and efficient heat storage technologies are needed to help to reduce Europe's demand for fossil fuels and facilitate a sustainable development.

Therefore a multi-national European consortium of partners from research and industry was formed to develop a new technology under the project name HeatSaver. Within the development of this project a high density heat energy storage module to enable the efficient and reliable thermo-chemical heat energy storage for temperatures above 100°C was developed. This technology features a number of advantages compared to sensible heat storage with water or latent heat storage with phase change materials:

- The energy density is higher and therefore the system will be much more compact than a water storage system which leads to a number of advantages like space savings and reduced system weight.
- The heat losses during storage are low since the heat storage principle is an adsorption/desorption process where the heat is not stored in a sensible way
- The temperatures for charging and discharging the storage can be adapted to the specific application.

The main objective of the follow up project, HS-DEMO, was to build up on the gathered technical expertise from the successfully finished HeatSaver project and to take the next step towards the market by realizing the adsorption heat storage technology as a closed demo-system to be tested in real industrial applications. This was done by designing and building two demo units which were tested at 3 different demo sites within the project.

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?

For thermal energy storage the physico-sorptive interaction between the reaction pair adsorbent (A) – adsorptive (B) with a preferably high energy turnover is utilized. This principle is reversible: A + B <–> AB + heat. To charge the storage medium, energy is added to a substance AB which then dissociates into A and B components. To recover the heat the A and B components have to react with each other again. As long as a reaction between A and B is prevented, the heat that is stored by physico-chemical phenomena cannot be readily released. The preferred adsorptive is water. It possesses a high phase transition enthalpy, is economic and harmless at the same time. The adsorbent selected (e.g. zeolite) has to bind the highest amount of water possible by adsorption.

Main objectives for the HS-DEMO project

1. To design an industrial manufacturing process for the zeolite based thermal storage system, capable to produce over one hundred units per annum. Two units to be produced with capacities ranging from 1m3 up to 10 m3
2. To monitor the operation of the two produced units in two different industrial applications for a period of over six months continuous operation. Key performance parameters to be monitored will include: power, storage capacity, temperatures, heat losses during charging/discharging and pressure.
3. To demonstrate the industrial scale zeolite based thermal storage units to over twenty industry representatives
4. To confirm the economic viability and environmental sustainability of the zeolite based thermal storage system according to a methodology based on ISO 14040 and ISO 14044 (2006)
5. To ensure continued IP protection for the benefit of the SME partners. To disseminate protected IP which will be undertaken to enable maximum commercialization of the results post-project, dissemination actions to include; five publications or conference proceedings and, presentations to at least two European industry trade shows

MAIN S & T RESULTS/FOREGROUNDS.

The HS-Demo project has successfully achieved a number of valuable scientific and technological results. The performed literature research and laboratory work in the former HeatSaver-project enabled a deeper understanding of the storage material characteristics, the thermodynamics and the physical background of the heat storage principle with regard to a real technological application. With this gathered Information it was possible to build two demonstration units in a relevant industrial scale to be tested in real applications. Thereby the limiting factors and the main challenges during integration and operation of such a storage system onsite 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 system parameterization and optimization of the process control, the heat exchange in/out of the bulk material, the gas flow conditions and the overall process design.

As the first step within the HS-DEMO project a re-evaluation of the existing knowledge has been performed to translate the technology into an economically viable replicable manufactured product in the future.
The project started with a detailed review and analysis of the knowledge created in the prior research and development project HeatSaver with the goal to gain a basis to proceed with the work on industrial manufacture of the technology leading to an improved and better system design. During the detailed review it was possible to identify technical improvements to achieve a better performance and to modify the system where needed in order to make it ready for a demonstration under real conditions. Therefore, within the HS-DEMO project the test unit from the HeatSaver project was renewed and improved by various measures in preparation for the demonstration activities to achieve process stability as well as an improved heat and mass transfer in the system. After the technical adaptation of the system, numerous dynamic charging and discharging test runs were carried out. Very significant improvements have been observed on the system in comparison to the initial state regarding temperature peak, heat storage density, heat power as well as the rate of charging and discharging processes.
Through the review and analysis on the design of the exiting test system, the project has already improved and optimized the heat storage technology. The optimized heat storage system has been used as the first demonstration unit (Demo-Unit-I).
The second demonstration unit (Demo-Unit-II) was built completely new, with a technical and economical optimized design, while the basic system set-up remained the same. Individual adaptation of the system mainly on the dimension of the storage reactor and evaporator/ condenser and their corresponding heat exchangers have been done depending on the foreseen charging and discharging temperatures. From the experiences made with the HeatSaver test system, an improvement on the design of the new Demo-Unit has followed. The storage volume of the Demo-Unit-II was increased to 1.5 m^3 compared to the Demo-Unit-I which has the storage volume of 0.75 m^3. The design was jointly made by the project partners, with every partner having the focus on his expertise. For the basic engineering of the system a newly programmed excel based tool was used. The tool contains the most important process parameters. In addition several approaches have been taken to achieve a standardization of the major part of the demo unit that included the storage reactor, internal heat exchanger, evaporator/ condenser, storage material for high temperature application, vapor riser channels, external heat exchanger and the measurement and control unit. The manufacturing of all required components to build this demo unit has been successfully done based on the developed concept. While the industrial manufacturing of the storage reactor, evaporator/ condenser and the external heat exchanger was carried out by the partner Dvigatel, the storage material, control system and vapour riser channels were manufactured by ZeoSys and B&O respectively in cooperation with their long-term external industrial partners.
As a part of the engineering of the demo unit, a list of the key components required building the system was elaborated. Thereby a significant cost reduction has been achieved in comparison to the former HeatSaver system. Since the system still contains numerous sensors to monitor the field tests and some components may even be improved in the future, further cost savings are expected for the next system generation.
Within the HS-Demo project parallel to the detail technical review, design and building of the demonstration units, an extensive site survey was performed in order to assess the suitability of a closed adsorption heat storage technology for application at different specific applications and to identify a number of potential end-users as well as to outline an agreement with the respective parties as a suitable demonstration site.

For that purpose a questionnaire has been set-up and site surveys have been conducted to acquire relevant data. Based on the collected data it was possible to determine a well suited demo site. These were then used to make a specific design for each selected site. The site survey process started with reviewing the existing data that were gained from the potential end users already identified during the HeatSaver project. The next step towards the site survey was collection of basic data by sending questionnaires to different new potential end users and other interested parties. This data was helping to understand the end-user requirements and boundary conditions as well as to evaluate the potential of the HeatSaver technology. Basic calculations and estimations were done to estimate the performance of a heat storage system in these specific applications as well as for future intended applications. Therefore a good background for dimensioning, adaptation and design of the demonstration units with respect to the required parameters was given.

A total of 50 potential end users were contacted through the survey questionnaires that have been distributed via e-mail and hard copies. Over 30 responses were received. Generally, the data on heat sources obtained during the site survey included a mix of solar energy, CHP plants, industry, and biogas plants. Around a third of the sites are using solar thermal energy installed in private and commercial housing. Final samples of 18 potential end users in the building sector as well as industrial areas were chosen based on pre-defined key evaluation criteria for identification of the best suitable sites. Finally based on a detail analysis of those obtained data, three most suitable sites were selected representing two different heat sources. At these finally selected demo sites, both heat source and consumer were available so that a good option was given to install a stationary demo unit.

The main heat source at the Demo Site I was an electrical oil heater. The stored heat was used for the purpose of the building space heating. The main heat source available for charging purpose at the Demo-Site-II is solar thermal collectors. Demo-Unit-I is tested in this application to serve as a compact and reliable part of the energy supply of a demonstration house. The aim of the integration of the adsorptive thermal energy storage system was to assist the establishment of a possible autarkic energy technique for areas in a winter garden. At the third demo site, where the Demo-Unit-II is installed, the main heat source is waste heat from saw dust burner. The stored heat is used for heating the hot water cycle used for production of domestic hot water as well as building heating purposes.

After designing, building phase was completed; the onsite integration of the Demo-Units was performed. At this stage appropriate installation set-ups were developed and installed for transferring thermal energy from the heat source to the storage reactor for charging as well as from the storage to the consumer for the discharging process. The installation of the storage Demo-Unit-I was done at two different demo sites in order to demonstrate the system for a longer period of time. Initially the demo unit was installed and integrated with the existing heating system of the Demo Site I during the wintertime for space heating application. Whereas during summer it was installed at the Demo Site II in order to test it in combination with solar energy for warm water supply.
During the following demonstration period, several charging and discharging cycles of both Demo-Units were successfully carried out. During the tests and demonstration activities different important parameters were measured and monitored. With the collected data, a detailed analysis was carried out which confirmed the expected system performance. Finally, it can be concluded that testing and demonstration of the two demo units have been successfully achieved. Nonetheless, further performance verification tests will be still needed.

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 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, 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 HeatSaver 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 HeatSaver 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 energy 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 HS-DEMO 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. The involved SMEs had several meetings and additionally reports were used to disseminate the knowledge created so far within the consortium. The objective was to ensure continued IP protection for the benefit of the SME partners and to disseminate protected IP to enable maximum commercialization of the results post-project. The first half of the project work focused on IPR management and the optimal route to dissemination and exploitation of the results to the defined targets as well as the establishment of exploitation management procedures for fast and coordinated market entry. In the second half of the project this work was intensified with the main focus on dissemination and exploitation of the project results. This was done via publications, discussions with potential customers, networking and presentation of the project results at congresses and fairs. These activities mainly built on the dissemination and exploitation activities of the previous HeatSaver project.

A complete revision of the project website provides general information about the project, the involved companies and the activities throughout the project. Additionally, information on the project is also provided on the respective company websites of the consortium.

A detailed and intensive patent research was done in the field of general and thermo-chemical heat storage system. It was partly an update on former searches but within the scope of the HS-DEMO a more widespread scanning of patents and keywords. With this information the “freedom to operate” in terms of future patents was identified. From the patent research altogether over 75 patents were found, from which 17 were analyzed in detail. A ranking of the patents according to their relevance with regard to HeatSaver technology was done. As a part of the plan for use and dissemination of foreground IP (PUD) a patent application preparatory process has been started. This includes proving whether the whole system or single components that were developed in the project (heat exchanger in sorption bed, reactor design etc.) can be patented. This process is performed together with a consultant who is specialized in patenting of innovations. The process is still ongoing.

Use and dissemination of foreground is systematically being tabled in reporting format in the draft of the PUD. The market approach detailed in the project proposal has therefore been re-evaluated and a crude SWOT (strengths, opportunities, weaknesses and threats) analysis was performed also in connection to the former described patent research. As market competition would potentially benefit from sensitive IP information from the project it is imperative that all information that needs to be shared is handled in an appropriate manner and channeled through the dissemination manager when there is a need to share with external partners. Publication of results was currently just done in a way that these do not contradict IP protection. If necessary the technical information was simplified to a level that IP protection was not negatively influenced.

Besides the actions that have been undertaken to spread the information to potential end users and other interested parties an evaluation and a questionnaire were announced and asked for user feedback.

Public website address:

http://www.heat-saver.eu/project-hs-demo.html

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