ADVANCED STORAGE CONCEPTS FOR SOLAR HOUSES AND LOW ENERGY BUILDINGS – IEA-SHC TASK 32

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ABSTRACT

This paper presents the current status of the work in Task 32 (Advance Storage Concepts for Solar and Low Energy Buildings) of the International Energy Agency's Solar Heating and Cooling Programme (IEA-SHC). A methodology for inter-comparison has been established and boundary conditions and reference systems for this have been defined. The current status of the projects range from recently concluded feasibility studies for chemical heat storage, to prototyping, lab testing, modelling and system simulation for advanced water stores, with and without PCM content, as well as for stores based on the sorption principle. Promising new components and solutions for more classical water tanks are also described in order to define market references.

1. INTRODUCTION

Solar thermal energy is widely used for space heating and domestic hot water heating throughout Europe as well as in Canada and other markets such as China. It can also be used to cool buildings in warm climates. United States, Japan, New Zealand and Australia have numerous examples of solar installations delivering both heating and cooling. Storage is a critical component of systems providing both space heating and hot water production ("solar combisystems"). In order to achieve high solar fractions both at an acceptable cost and in a "marketable" volume, solar energy researchers convened a workshop on the status of advanced solutions for storage of solar heat. The workshop resulted in the establishment in late 2003 of Task 32 (Advance Storage Concepts for Solar and Low Energy Buildings) of the International Energy Agency's Solar Heating and Cooling Programme (IEA-SHC).

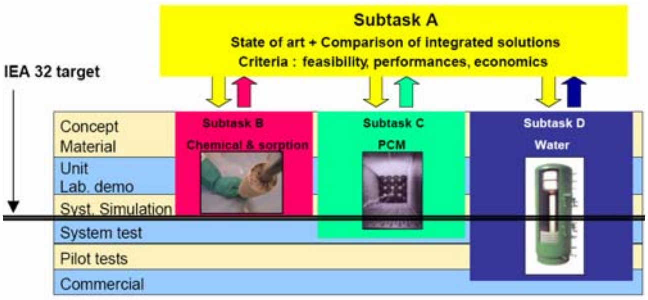

Fig. 1: Organization of IEA-SHC Task 32.

The main goal of the Task is to investigate new or advanced solutions for storing heat in systems providing heating or cooling for low energy buildings. The first objective of the Task is to contribute to the development of advanced storage solutions in thermal solar systems for buildings that lead to high solar fraction up to 100% in a typical 45N latitude climate. The scope of the Task is restricted essentially to single family houses. The work of the Task is split into four different areas (see Fig. 1), one for evaluation and dissemination and one each for the different storage media: water; phase change materials (PCM); and chemical storage including sorption. There are participants from eight different countries as well as several companies in the Task, which is active over the period June 2003 to December 2006. Four expert meetings have taken place so far. More information about Task 32 can be found at the website www.iea-shc.org.

The different technologies are at different stages of development technically and commercially. The Task will therefore compare the technologies based on system simulations. However, a number of other criteria such as environmental impact and estimated costs will also be considered. A methodology for inter-comparison has been established and boundary conditions and reference systems for this have been defined. A state of the art book on the subject has been compiled and is in printing.

2. CHEMICAL STORAGE INCLUDING SORPTION

For chemical storage, heat is required in an endothermic process to split compounds into several products. For a cyclic process, the products of the reaction or sorption process have to be reconverted to the original compound in an exothermic reaction, where heat can be utilized for the load. The exothermic reaction is generally at a lower temperature than that of the endothermic reaction. Many compounds result in products that can be stored over long periods without significant energy losses, making long term heat storage possible.

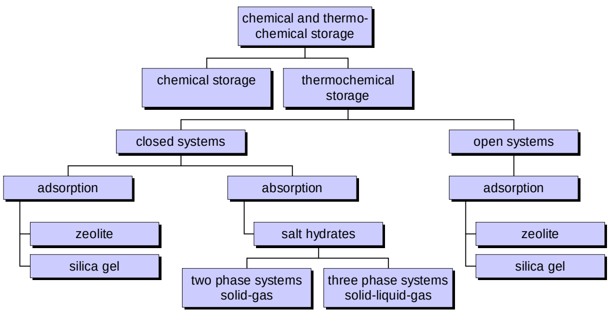

Fig. 2: Chemical and thermo-chemical storage using sorption.

In Task 32, nearly all projects focus on storage using sorption with water as the sorbate and a range of materials as the sorbent (see Fig. 2.). The processes are either closed, with storage of both sorbate and sorbent under vacuum, or open where the sorbate (water) is released to ambient in the desorption (endothermic) process and then extracted from ambient during recombination (exothermic process). Fig. 3 shows schematically the desorption, or charging process, at temperature T with the sorbate being driven off and condensed in a separate vessel at a lower temperature (T'). Both adsorption (physical bonding) and absorption (chemical bonding) are found in the systems being studied, which are summarized in the following subsections. All closed systems act as chemical heat pumps, requiring "free" energy from the ambient at a relatively low temperature, which is upgraded by the sorption process to a higher temperature. As all the studied closed systems use water, this free energy must be at a temperature greater than approx. 5°C.

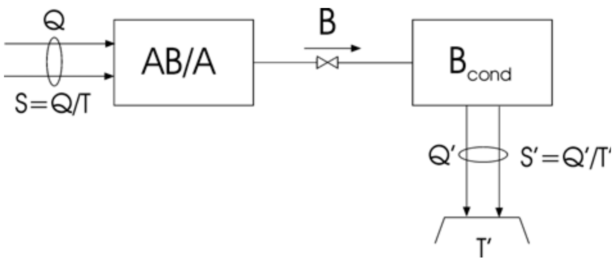

Fig. 3: Indirect heat storage by way of a reversible closed system sorption process with condensation of the gaseous working fluid. (1)

The main **advantages** of chemical storage including sorption:

- High energy density resulting in small volume of material.
- Many systems act as heat pumps making cooling as well as heating possible.

The main **disadvantages**:

- Greater complexity in the system (closed systems).
- Many compounds are relatively expensive.
- Relatively high temperatures required.
- Limited experience with long-term operation (after many thousand cycles).

2.1 Monosorp - Open Adsorption System using Heat Recovery Unit (ITW. University of Stuttgart, Germany)

This simple open system (2) consists of a zeolite store with honeycomb construction, that uses heated air for desorption and moisture from the indoor air for the adsorption stage. Heat is recovered at all times using the house's heat recovery unit. Initial simulation results show 70% energy savings for a house with 7600 kWh (25.9 GJ) heating and DHW load, using a 1 m^3 water store, a 7.6 m^3 zeolite store together with 20 m^2 CPC evacuated tube collector. To get the same savings a water store of 20 m^3 would require 50 m^2 collector.

2.2 TCA – Thermo-Chemical Accumulator (SERC, Dalarna Univ. College, Sweden)

This is a closed absorption heat pump system (3) using three phases: solid, solution and steam. During desorption, saturated solution is pumped over a heat exchanger, where crystals are formed. These then drop under gravity into a container and are physically restrained by a sieve. The desorbed water is condensed in another vessel. Absorption is essentially the reverse process, with saturated solution pumped over the heat exchanger where it absorbs water before percolating through the crystals to make the solution saturated once again. The process is being developed by the Swedish company ClimateWell. The storage capacity of the prototype machines is only 70 kWh heat at a rate of 8 kW, resulting in low energy density if the volume of the heat exchangers and other vessels is included in the calculation. The energy density based on the volume of the solution at its most dilute stage is 330 kWh/m^3 (1.2 GJ/m^3). A model of the TCA process is being developed and validated, and will be used to simulate systems with both long and short term storage.

2.3 Adsorption Store (SPF, Hochschule für Technik Rapperswil, Switzerland)

This project aims to develop a closed adsorption store with minimum number of moving parts. It will act as a thermally driven heat pump with a capacity of 5 kW. Detailed measurements have been made of temperature and water uptake profiles as a function of time as well as energy density as a function of temperature. The system is in the design stage with an expected prototype being tested in the lab before the end of the Task.

2.4 Modestore (AEE-Intech, Austria)

This is essentially part of a European project (4,5) which aims to develop closed adsorption heat pumps and stores. The majority of the effort is on heat pumps, but one partner is working on stores with the aim of reaching nearly 100% solar fraction in a low-energy single family house. One of the goals of the project is to minimize the number of vacuum connections in order to reduce costs. The key components (silica gel packing, heat exchanger, evaporator/condenser) are integrated into a single container. The laboratory-scale unit currently under investigation has a total volume of 350 l and has been tested in the lab. The results show good function in desorption mode but a requirement for improved control during adsorption. A simulation model has been made and is being validated against the measurement data before it is used for designing a full scale demonstration plant which will be installed later this year (2005).

2.5 Compact Chemical Heat Store (ECN, Holland)

This project aims to develop a chemical heat store for domestic seasonal storage 8300-1100 kWh (30-40 GJ) with the endothermic reaction in the range 60 - 250°C. A preliminary study (6) has been completed, where a range of criteria were set up for ranking different materials in the context of the project's aims. A "realization potential" was calculated based on these criteria. Basic simulations models were developed and annual simulations were carried out. The study showed that Magnesium Sulphate had the best realization potential, followed by Iron Carbonate, Iron Hydroxide and Calcium Sulphate. These had storage densities of 390-780 kWh/m^3 (1.4-2.8 GJ/m^3). A fifth compound, Silicon Oxide was also ranked highly, but requires a very high temperature unless Hydroflouric acid is used. It is planned to carry on with design of a prototype store for either Iron Hydroxide or Magnesium Sulphate.

3. PHASE CHANGE MATERIALS (PCM)

3.1 Introduction to PCM

The thermal energy absorbed by a material when changing its phase at a constant temperature is called 'latent heat'. For practical applications, materials that exhibit low volume changes are used, for example, solid-to-liquid and some special solid-to-solid phase change materials are applicable. In 1983 Abhat gave a useful classification of the substances used for thermal energy storage (see Fig. 4).

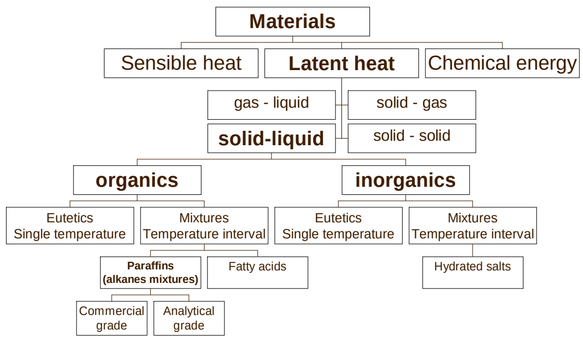

Fig. 4: Classification of PCM Materials (7).

The commonly used phase change materials for technical applications are: paraffins (organic), salt hydrates (inorganic) and fatty acids (organic). For cooling applications, it is also possible to use ice storage.

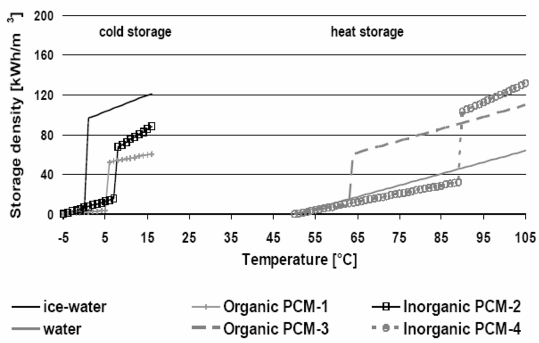

Fig. 5: Storage density of different PCM's in comparison to water-ice (cold storage) and pure water (8).

Fig. 5 shows materials for storage application in the low temperature range (cold side) and materials for heat storage application (hot side). Latent heat storage offers a significant advantage if the application needs temperature cycles near to the Phase Change Temperature (PCT), as in those cases the corresponding storage density of water is small.

Possible Applications in Solar Buildings for PCM are:

- Cold storage for solar assisted cooling applications (PCT around 5 -18°C).
- PCM (Micro-Capsules) incorporated in wall material (PCT around 22°C).
- Heat storage for Solar Energy and longer running time of boilers (PCT around 60°C).
- Hot storage for Solar Assisted Air Conditioning (PCT around 80°C).

In all cases, heat must be transferred between the phase change material and the fluid cycle (charging, discharging). Different techniques are used, including:

- Direct contact between phase change material and heat transfer fluid: this needs materials that are chemically stable for long periods of direct contact and the solidification of PCM occurs in small particles, preventing sufficient heat transfer during subsequent melting.
- Macroscopic-capsules: this is the most frequently used encapsulation method. The most common approach is to use a plastic module, which is chemically neutral with respect to both the phase change material and the heat transfer fluid. The modules typically have a diameter of some centimetres.
- Micro-encapsulation: this is a relatively new technique in which the PCM is encapsulated in a small shell of polymer materials with a diameter of some micrometers (at the moment only for paraffins). This results in a large heat-exchange surface and the powder- like spheres can be integrated into many construction materials or used in an aqueous pumpable slurry. Plasters with micro-encapsulated PCM are on the market since 2004. PCM-slurries are still under development.

The main **advantages** of phase change storage in comparison to conventional water storage techniques are:

- Higher thermal energy storage capacity (smaller storages) than sensible energy storage, at least if only small useful temperature differences are used.
- Relatively constant temperature during charging and discharging.

The main **disadvantages** of phase change storage are:

- Higher investment cost, in most cases, compared to water storage.
- In many cases, the peak power during discharge is limited due to limited heat conduction in the solid state of PCM. This is the main limit determining the acceptable size for the storage modules.
- Limited experience with long-term operation (after many thousand cycles).
- Risks of loss of stability of the solution and deterioration of the encapsulation material.

3.2 PCM related projects in IEA-SHC Task 32

There are five PCM related projects included in Task 32: Three projects deal with macro-encapsulated PCM containers in water stores. All of these projects include the development of TRNSYS models for the PCM stores:

- In Lleida University (Spain) bottles of PCM material with graphite matrix for the enhancement of the heat conduction and increase of power input/output is tested. Applications are free-cooling and DHW tanks
- In the Applied University of West-Switzerland in Yverdon les Baines (Switzerland) a parametric study for the use of PCM in heat stores for solar combisystems is carried out.
- The Institute of Thermal Engineering at Graz University of Technology (Austria) performs tests and simulations with different PCM materials encapsulated in plastic foils for stores for conventional boilers to increase the cycle time, reducing numbers of starts/stops and thus CO and HC emissions.

The two other projects are slightly different

- In the Department of Civil Engineering, Technical University of Denmark the use of super cooling of PCM materials for long-term heat storage is investigated with simulations.
- The Institute of Thermal Engineering at Graz University of Technology (Austria) performs tests and simulations with PCM-slurries of micro-encapsulated paraffins for heat storage with conventional boilers to increase the cycle time.

4. ADVANCED WATER STORES

The storage of thermal energy by using hot water stores is already common practice for many decades both in the HVAC sector and for industrial applications. Nevertheless during the last 20 years the major research activities in the field of hot water stores were carried out with regard to solar thermal applications. Today hot water stores are produced in large quantities and are part of nearly every thermal solar system.

The most important advantages of water as storage medium are:

- Environmentally friendly.
- Inexpensive and easy to handle.
- High thermal capacity.

- Decreasing density with increasing temperature and low thermal conductivity. This offers the possibility of stable thermal stratification.
- Long term experience available.

Although the technical level of water stores is already quite high, there is still room for further improvements. The focus of the Subtask dedicated to „advanced water stores“ is on advanced storage systems including new solutions for specific components such as the tank material, stratification enhancers or the improvement of the thermal insulation. The usage of a combination between water and PCM materials as heat storage medium will also be investigated. Furthermore the interaction of the store or the whole system respectively with different auxiliary heat source (gas or oil burners, fuel cells) and control strategies will be analysed.

The following sections summarize the work of the different research group's contribution to this Subtask:

4.1 Laboratory tests of inlet stratifiers (Dept. of Civil Engineering, Technical University of Denmark)

In order to improve the thermal stratification in solar storage tanks stratification devices are used. The task of these devices is to feed the incoming water in a "layer" with a temperature approximately similar to the one of the incoming water.

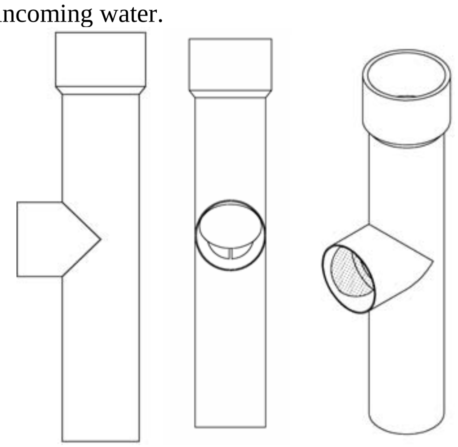

Fig 6: Solvis stratifier.

One well known manufacturer of such a stratification device is the German company Solvis. Within the project laboratory tests of Solvis inlet stratifiers (see Fig. 6) have been carried out (9).

4.2 Solar goes CFD (ITW, Univ. of Stuttgart, Germany)

The overall goal of this project is to pave the way for CFD calculations (CFD: Computational Fluid Dynamics) as an optimisation and design tool for solar hot water stores (10). In order to prove the validity of the software and to determine the appropriate simulation parameters (e. g. sizing of grinds, turbulence models) as a first step numerical simulations with the software FLUENT are carried out and compared with experiments. Quantitative information about the flow fields inside the hot water tank is determined by means of PIV (Particle Image Velocimetry). Fig. 7 shows an example where the velocity difference in the "u"- direction between measurements and calculations are plotted for a flow field caused by a jet directly entering a hot water tank with inlet temperature of 60 °C and store temperature 20 °C.

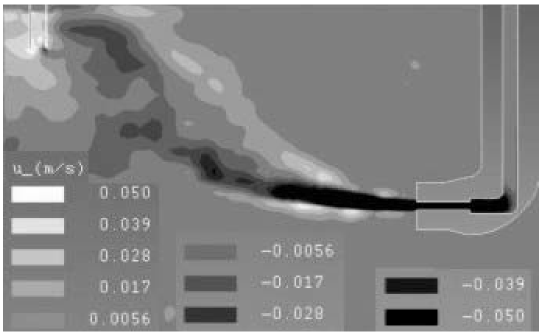

Fig 7: Example of comparison of measured and calculated velocity fields.

4.3 Insulation materials for advanced water stores (Dept. of Civil Engineering, Technical University of Denmark)

An investigation on different insulation materials that may be of interest for the thermal insulation of solar storage tanks was carried out. The main results from the state of the art work on insulation materials are: Polyurethane foams can be made with a thermal conductivity as low as 0.024 W/(mK) if the foaming process is well controlled. Further improvement of the tank insulation can only be achieved by means of vacuum insulation, which however is difficult to apply. One promising solution is to have vacuum insulation panels embedded in the traditional PU foam insulation, in which case the heat loss coefficient can be reduced with 50% compared to common PU foam insulation with the same thickness.

4.4 Investigations of combined water/PCM stores (Univ. of Lleida, Spain)

The content of the project is the analysis and implementation of thermal energy storages with phase change materials for two applications: free-cooling and domestic hot water preparation. A tank with a nominal water volume of 146 litres was equipped with PCM. The percentage of PCM (from 2 to 6% volume) and the type of PCM was varied. Furthermore a TRNSYS model was developed in order to describe the thermal behaviour of the water/PCM tank and to compare the performance with a reference hot water tank. Based on some first experiments the results look quite promising. As a next step more experimental tests will be performed in a pilot plant. Furthermore the TRNSYS model will be validated.

4.5 Simulation Study on advanced storage concepts for solar combisystems (ITW, Univ. of Stuttgart, Germany)

In Germany today standardised solar combisystems consist of a solar collector with an area between 10 m^2 to 20 m^2 and a hot water storage tank with a volume in the range of 0.7 – 1.5 m^3. If such systems are installed in a „typical“ middle European single family house, they can save approximately 20 - 30 % of the primary energy required for domestic hot water preparation and space heating. In order to increase the energy savings, larger collector areas and/or store volumes are required. By means of a simulation study it was investigated what fractional energy savings can be achieved by using different types and sizes of solar collectors and heat stores (11). The base case for the simulation was a single family house located in the middle of Germany (Würzburg) with annual loads for space heating of 9090 kWh (32.7 GJ) and for domestic hot water preparation 3590 kWh (12.9 GJ).
The key aspect of the simulation study was related to advanced water stores (e. g. improved thermal insulation). In order to asses and compare the results to other storage technologies PCM stores and closed sorption stores were also taken into account.

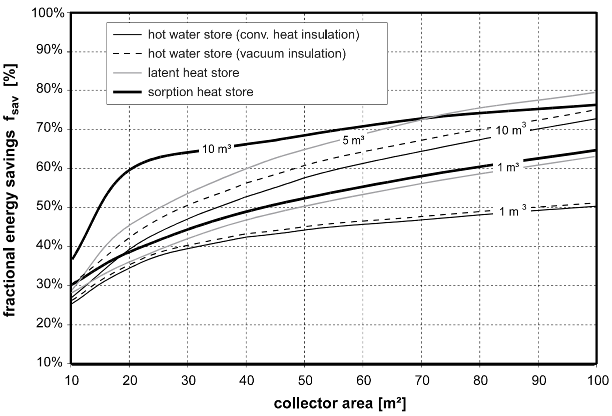

Fig. 8: Fractional energy savings for different store technologies and volumes (in addition to a “conventional” combistore of 750 litres).

Fig. 8 shows the factional energy savings that can be obtained by using flat plate collectors in combination with different store technologies and volumes.

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