Towards seasonal heat storage based on stable super cooling of sodium acetate trihydrate

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Abstract

Small scale laboratory experiments have been carried out with the aim of elucidating how best to design a seasonal heat storage based on the salt hydrate sodium acetate trihydrate. The heat storage will be suitable for solar heating systems, which can fully cover the heat demand of low energy buildings under Danish conditions.

The heat storage concept is based on the advantage of stable supercooling of the salt hydrate to achieve a partly heat loss free heat storage.

Based on the experiments, a laboratory heat storage module was built. The module will be tested in 2010. It is expected that a 1000 l laboratory seasonal heat storage will be built and tested in 2011.

1. Introduction

Theoretical investigations have shown that a 36 m² solar heating system can fully cover the yearly heat demand of a low energy house in Denmark if the solar heating system is based on a 6000 l seasonal heat storage with sodium acetatate trihydrate supercooling in a stable way. The heat storage is divided into a number of separate modules.

The heat storage concept is based on the advantage of stable supercooling to achieve a partly heat loss free heat storage. If sodium acetate trihydrate, which has a melting point of 58°C, has been fully melted, it can cool down in its liquid phase to the surrounding temperature and still preserve the latent heat related to the heat of fusion. The heat storage can be left in this state with no heat loss until a heat demand occurs, in which case solidification is activated, the heat of fusion is released, and the heat storage temperature increases almost immediately to the melting point.

During participation in the IEA Task 32 project “Advanced storage concepts for solar and low energy buildings” in the period 2003-2007, a good basis for development of such a seasonal heat storage was established, [1-9].

The investigations described in this paper are carried out within the IEA Task 42 project “Compact Thermal Energy Storage: Material Development and System Integration”.

2. Small scale laboratory experiments

Before designing a seasonal heat storage based on sodium acetate trihydrate, the following questions have to be answered:

- Which heat storage temperature level is needed during charge periods in order to achieve a stable supercooling of the heat storage material?
- Can the heat storage material supercool in tanks with large volumes?
- What is the optimum size of each module consisting of one separate container of the heat storage?
- How is the supercooled salt solution activated in the most reliable way?
- How are large quantities of the salt water mixture best filled into the modules of a heat storage?

The questions were answered by a number of small scale laboratory experiments. The heat storage material in all the experiments is a mixture of 58% (weight %) $NaCH_3COO$ and 42% (weight %) water. Experience has shown that this mixture, which has a melting point of 58°C, supercools in a stable way.

A large number of experiments with small amounts of the heat storage material placed in small glass containers were carried out. The glass containers were first heated from the ambient temperature to different constant high temperatures in a heating chamber. The glass containers were kept at the constant high temperature for 2 days. After that, the glass containers were left alone at an ambient air temperature of 20°C for a long period. The experiments showed that the mixture supercools in a stable way, as long as the mixture is heated to a temperature not lower than 64°C. If the mixture was heated to a temperature in the interval from 58°C to 64° the mixture did not supercool.

279 kg of the salt water mixture placed in a plastic tank was heated from 20°C to 80°C in a heating closet. By the end of the heating period the temperature of the whole volume of the tank was 80°C. After that, the tank was left alone at an ambient air temperature of 20°C for a long cool down period. The test was repeated many times, and for all tests the salt water mixture supercooled to 20°C without one single failure. The mass of the salt water mixture corresponds, at a salt water mixture temperature of 80°C, to a volume of about 215 l. Obviously, it is not a problem to achieve stable supercooling for a heat storage volume of 215 l.

Further, theoretical investigations have shown that an optimum size of each module of a seasonal heat storage for a solar heating system is placed in the interval from 250 l to 500 l, [8]. Based on this, on the experiments with the plastic tank and on practical considerations, it was decided to build and test a laboratory module of a seasonal heat storage with a volume of about 230 l.

Small scale laboratory cooling tests were carried out with about 100 g supercooled salt water mixture placed in two small glass containers in order to elucidate the temperature, where supercoling is not longer possible. The glass containers were placed in a freezer and the temperatures of the salt water mixtures were measured. It appear, that the minimum temperature, where the salt water mixture is still supercooled, is placed between -15°C and -16°C. This is in good agreement with earlier investigations [10], [11].

That is, solidification can be started by cooling down a part of the supercooled salt water mixture to a temperature below -16°C.

Small scale experiments were carried out using CO_2 in the liquid phase from a pressure container to cool down a part of a supercooled salt water mixture with the temperature 20°C. A schematic sketch of the setup is shown in figure 1. A small cylindrical copper tank with an inner volume of about 1.2 cm^3 is placed in a small glass container with a supercooled salt water mixture. The length of the copper tank is 1.5 cm, and the inner and outer diameters are 1.0 cm and 1.2 cm respectively. From the pressure container the liquid CO_2 can flow through a pipe with a pressure reducing valve into a small pipe which is connected to the cylindrical tank.

The cylindrical copper tank is equipped with another small pipe connected to the top of the tank. At the top of this pipe, a back pressure valve and a pipe for gas escape are placed.

The pressure reducing valve and the back pressure valve secure that the pressure in the pipe system and the tank is constant at about 5 bar. Liquid CO_2 from the pressure container flows into the cylindrical copper tank, where it boils at about -78°C.

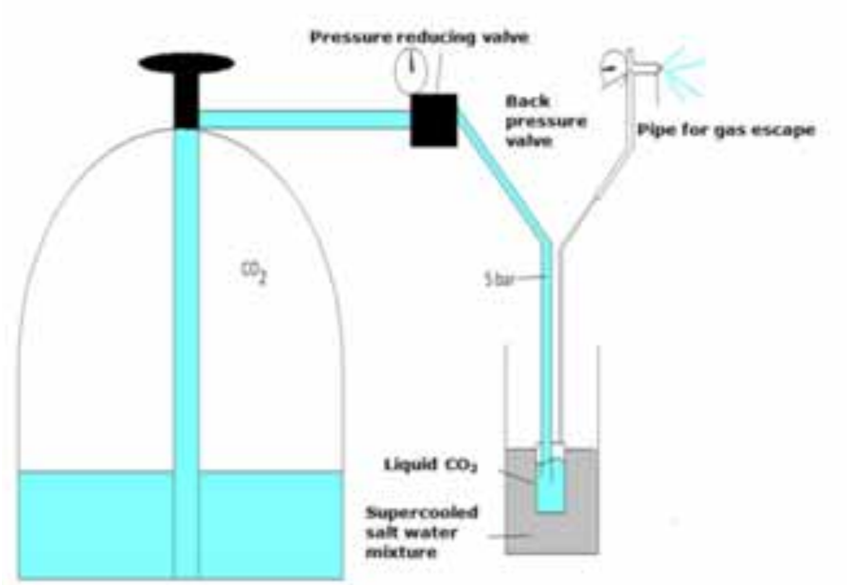


Fig. 1. Schematic sketch of the setup used to cool down a part of a supercooled salt water mixture.

The liquid CO_2 in the cylindrical copper tank boils at about -78°C due to the heat transfer from the surrounding supercooled salt water mixture. The evaporated CO_2 will escape from the pipe system as gas through the pipe for gas escape. The high latent heat of the phase change from liquid to gas of CO_2 will secure a high heat transfer from the salt water mixture resulting in a strong decrease of the temperature of the salt water mixture in direct contact to the copper tank. Figure 2 shows photos of the setup.

The results of the tests with the setup are very promising. A small part of the salt water mixture cools down so quickly that the solidification started 1-2 seconds after starting the CO_2 flow from the pressure container to the piping system.

The above described method to start solidification is further investigated: Maybe solidification can be started by cooling a small part of the salt water mixture in a container through the container wall? If that is possible, the inner part of the container can be fully reserved for the salt water mixture making the heat storage design relatively simple and cheap.

Instead of a cylindrical copper tank placed in the salt water mixture, a small brass tank is in good thermal contact attached to the outer side of a 2 mm steel plate representing a container wall, see figures 3 and 4. Supercooled salt water mixture with a temperature of 20°C is placed in a glass container separated from the brass tank by the steel plate. The solidification start method described above is investigated by means of tests with this setup. Also for this setup, the method is successful. The solidification started less than 30 seconds after starting the CO_2 flow from the pressure container to the piping system. It is concluded that the solidification start method is promising, and it will be tested in full scale tests.

Large quantities of the salt water mixture can be heated in plastic tanks in a heating closet to a temperature of about 80°C. The salt water mixture can then by means of a normal circulation pump and plastic hoses be pumped from the plastic tank into the modules of a heat storage, see figure 5.

Further, the plastic tank can be equipped with a pipe connection at the bottom. Such a pipe connection can be used to empty the tank and fill a heat storage module by means of a connecting hose and the gravitational effect.

Fig. 2. Photos of the pressure container, the pressure reducing valve, the pipe system and the glass container.

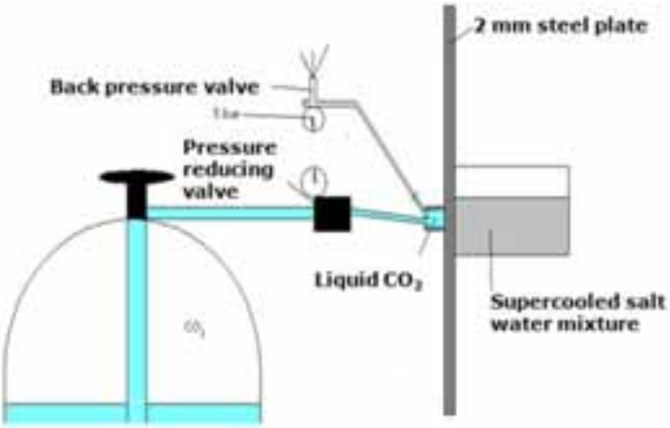


Fig. 3. Principle sketch of the setup with cooling through a steel plate.

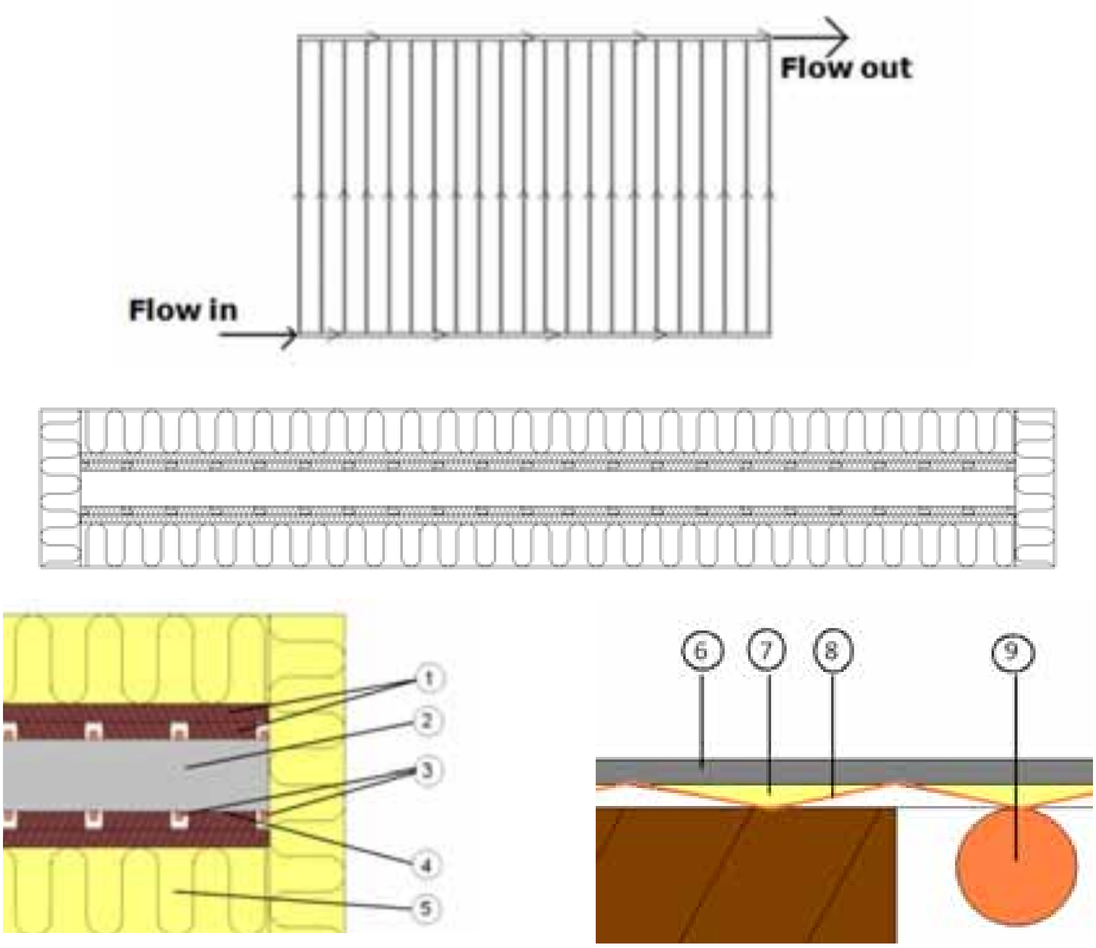
Fig. 4. Photos of the setup with cooling through a steel plate.

Fig. 5. Salt water mixture from a plastic tank pumped into a heat storage module.

3. Laboratory heat storage module

A laboratory heat storage module with a salt water mixture volume of about 230 l was built. Figure 6 shows a schematic sketch of the heat storage module with approximated dimensions in mm. The module material is steel and the wall thickness is 2 mm. Both the upper and lower surfaces of the flat module are used as heat transfer areas for heat transfer to and from the module. Water, which is used as the heat transfer fluid, is pumped through two copper absorbers placed below and above the module as shown in figure 7. Wooden slats are placed above and below the absorber strips in such a way that there will be a good thermal contact between the fins and the module surfaces. The construction is insulated with 100 mm mineral wool.

Fig. 6. Principle sketch of heat storage module with two holes used to fill in the salt water mixture.



1: Wooden slats. 2: Salt water mixture in steel module. 3 & 9: Copper pipes. 4 & 8: Absorber fin. 5: Mineral wool. 6: Bottom of module. 7: Paste with good thermal conductivity.

Fig. 7. Principle sketch of heat storage module with heat transfer system and insulation.

The module is filled with 305 kg salt water mixture corresponding to a module volume of about 230 l. Figure 8 shows photos of the module inclusive thermocouples for measurements of the module surface temperatures. The flat module is placed with a small tilt from horizontal. A small brass tank is in good thermal contact attached to the outer side of the module wall at the lowest part of the module. In this way the solidification start method described in section 2 can be tested.

Fig. 8. Photos of the heat storage module.

4. Planned activities

The laboratory heat storage module described in section 3 will be tested in a heat storage test facility. It will be elucidated if the salt water mixture will supercool. The CO_2 solidification start method will be tested in full scale and the heat storage capacity and heat loss of the module will be determined. Further, the heat exchange capacity rate during charge and discharge for the heat storage module will be determined, both with heat transfer through one and two module surface(s).

Based on the tests and on the experience from operation of the module, recommendations for the design of a seasonal heat storage will be given. Among other things, suitable module and heat exchanger designs and materials will be determined. It will also be elucidated which control system is most suitable for the heat storage.

A 1000 l laboratory heat storage will be built based on these recommendations. The heat storage will be tested in a laboratory test facility. The operation of the heat storage will be simulated as if the heat storage is a part of a solar heating system.

5. Conclusions

Small scale laboratory experiments have elucidated that a salt water mixture of 58% $NaCH_3COO$ and 42% water with a melting point of 58°C supercools in a stable way as long as it is heated to 64°C during charge periods.

The salt water mixture supercool in a stable way in tanks with a volume of 215 l. A solidification start method based on a cooling of a small part of the salt water mixture to a temperature level below -16°C was developed. This cooling is based on boiling CO_2 in a tank attached in a good thermal contact to the outer surface of the heat storage module in which the salt water mixture is placed.

Based on the experiments a laboratory heat storage module with a salt water mixture volume of 230 l was built. The module will be tested in 2010. It is expected that a 1000 l laboratory seasonal heat storage will be built and tested in 2011.

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