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Laboratory test of a prototype heat storage module based on stable supercooling of sodium acetate trihydrate

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Abstract

Laboratory test of a long term heat storage module utilizing the principle of stable supercooling of 199.5 kg of sodium acetate water mixture has been carried out. Avoiding phase separation of the incongruently melting salt hydrate by using the extra water principle increased the heat storage capacity. An external expansion vessel minimized the pressure built up in the module while heating and reduced the risk of instable supercooling. The module was stable supercooled at indoor ambient temperature for up to two months after which it was discharged. The energy discharged after activating the supercooled sodium acetate water mixture was 194 kJ/kg of sodium acetate water mixture in the first test cycles dropping to 179 kJ/kg in the later test cycles. Instability of the supercooling occurred when the charging periods were short and in the last test cycles where the tube connecting the module to the expansion vessel had been blocked by the salt hydrate.

Keywords: Seasonal heat storage, sodium acetete trihydrate, supercooling, prototype testing, thermal energy storage

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1. Introduction

Heating buildings and domestic hot water usage accounts for a large part of our energy use. Solar energy is more abundant in summer than in the winter periods when heating demands are much larger. Thermal energy storage technologies are therefore needed to match the intermittent supply of solar energy with varying heating demands. Currently available heat storage systems that use water as the storage medium work well but mainly for short term

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storage, as their continuous heat losses limit the storage period. For long storage periods alternative technologies are needed. Storages utilising the latent heat of fusion of a material has been suggested for improving the performance compared to the storage of sensible heat [1]. Subcooling/supercooling of Phase Change Material (PCM) in the latent heat storage has been seen as an undesired effect that had to be avoided by using various nucleation agents as it prevented the heat of fusion from being released as desired when the melting point of the storage material was reached during the discharge process [2]. The idea of utilizing a supercooled salt hydrate for long term storage has however been known since the late 1920s [3] and pocket-sized heat packs storing heat in supercooled sodium acetate trihydrate were patented in 1976 [4]. Well-functioning large scale applications utilizing supercooled PCM for long term storage have not previously been reported.

Sodium acetate trihydrate with a melting point of 58°C and a relatively high heat of fusion of 264 kJ/kg [5], have been shown to supercool consistently down to temperatures well below 0°C [6, 7]. As sodium acetate trihydrate is an incongruently melting salt hydrate it will tend to suffer from phase separation especially over repeated heating and cooling cycles, which will reduce the storage capacity [3, 8]. Adding extra water to the salt hydrate so that the salt water mixture composition is always at a point where all salt is dissolved in the water when it is in the supercooled liquid phase has been proposed as a solution [9, 14]. This requires soft mixing of the salt water mixture to avoid phase separation and it reduces the energy density of the storage.

When the ever-present impurities in the salt hydrate work as nucleation agents, large PCM volumes may show reduced stability of the supercooling, as the chance of a spontaneous nucleation caused by an impurity increases with the volume [7]. Heating the salt water mixture to a high temperature will cause some evaporation of the crystal water, so a closed container with no loss of water through the tank material over the lifetime of the storage unit is essential to avoid changing the composition of the salt water mixture. As the metastable state of the supercooled salt hydrate could easily be interrupted by external influences, a closed container is inherently more stable. Diffusion of the heat transfer fluid from the heat exchanger into the PCM should be avoided. When considering the choice of tank material, corrosion and chemical reactions between the salt and the tank material must be considered. Steel and stainless steel in combination with sodium acetate trihydrate has been shown to be stable over long periods [10]. When using rigid constructions such as steel the density change between the cold solid and the warm liquid salt hydrate must be considered, as the volume change of the PCM in a closed container can cause pressure changes and deformations of the tank. Just as bending a metal disk with cracks works as a triggering mechanism for the pocket sized heat packs [11], small cracks on the inside of the tank can in combination with pressure changes and deformations work as an uncontrolled activation mechanism e.g. at joints or weldings. The volume reduction that takes place in sodium acetate trihydrate when changing from the liquid to the solid state could form cavities inside the tank that reduce the heat transfer rate between the PCM and the heat transfer fluid [5].

To achieve supercooling of the sodium acetate water mixture it is necessary that all crystals of the bulk are melted so that the sodium acetate water mixture will not crystallise as it cools down. There appears to be a link between the level of heating above the melting point and the stability of supercooling [12], and a temperature of around 20 K above melting point is needed in the entire volume to achieve stable supercooling.

Crystallization and release of the heat of fusion from the supercooled sodium acetate trihydrate is initialised when the first seed crystal of a certain size is present in the solution, after which the crystallization will spread to the entire volume and the temperature will rise to close to the melting point of 58°C [7]. Supplying the seed crystal to trigger the crystallization in a reliable and controllable way is essential for such a system. Ultra-sonic sound has been tried and found reliable as an activation mechanism [13]. The metallic disc of the pocket sized heat packs also works reliably but needs moving parts submerged in the solution and therefore also poses a risk of uncontrollable activation. Mechanically dropping a crystal into the supercooled solution might also be a viable solution. Lastly, it has been shown that cooling a supercooled sodium acetate water mixture to a low temperature will eventually cause crystallization of the supercooled solution [6].

As the entire volume will crystallize once it is activated, it is desirable to divide the storage unit into a number of separate modules that can be operated individually. The size and number of modules would depend on the application into which it is to be integrated.