Compact seasonal PCM heat storage for solar heating systems

Space heating of buildings and preparation of domestic hot water accounts for a large part of the society’s energy consumption. Solar radiation is an abundant and renewable energy source which can be harvested by solar collectors and used to cover heating demands in the built environment. The seasonal availability of solar energy does however not match with the heating demands in buildings which typically are large in winter periods when limited solar energy is available. Heat can be stored over a few days in water stores but continuous heat losses limit the storage periods. The possibility of storing heat from summer where solar energy is widely available to winter periods where the heating demands are large, allows for implementing more renewable energy in our energy system.

The phase change material (PCM) sodium acetate trihydrate (SAT) melts at 58 °C. The melting process requires a significant amount of energy. When completely melted, SAT can cool down below the melting temperature and remain in liquid state. When the SAT remains in this supercooled state at ambient temperature, the energy used for the melting process is stored without any additional heat losses occurring. When the solidification of the supercooled SAT is started, the temperature of the SAT rises to the melting temperature and the stored heat is released. Utilizing this principle makes it possible to store heat seasonally.

A number of problems, barriers and proposed solutions for operating a storage based on stable supercooled SAT have been identified. Key problems include phase separation of SAT which causes the heat storage potential to be reduced over repeated heating and cooling cycles. This problem can be reduced by making PCM composites of the SAT with extra water or thickening agents. Another key problem is achieving stable supercooling of the PCM in the storage period. The supercooling stability can be compromised by local high pressures in the storage tanks or by external particles coming in contact with the supercooled SAT. A closed PCM chamber which can operate with minimal pressure changes caused by the changing density of the SAT during heating and cooling have shown increased stability of supercooling.

Two differently designed heat storage prototypes in steel and stainless steel with different PCM composites have been tested under controlled laboratory conditions. One design was a flat rectangular unit consisting of a 5 cm high PCM chamber with heat exchangers on the outer surfaces. This design was tested with 200 kg SAT with extra water and with 220 kg of SAT with the thickening agent carboxymethyl cellulose. Supercooling was stable for up to two months in one test with this unit when an external expansion device allowed for operating the storage with minimal pressure built up. Stable supercooled failed in some test cycles.

Cylindrical shaped units with a height of 1.5 meters were tested with 116 kg SAT with extra water and with SAT with the thickening agent Xanthan rubber. Supercooling was achieved for shorter periods in these units in few of the test cycles. Spontaneous solidification started in these prototypes due to the design of the inner surfaces of the PCM chamber and the method for handling the expansion of the PCM.

By testing the prototype units it was found that the heat content of SAT with extra water was reduced over the repeated test cycles. The heat contents of the SAT mixtures with thickening agents were stable over the test cycles. Higher heat content and discharge powers were achieved in the units with SAT and thickening agents. The heat transfer was lower in the units with SAT and thickening agents during charge due to a reduced heat transfer by convection in the thickened PCM.

Investigations by a simple heat loss method on samples of 200 g SAT with additives have elucidated possible ways to avoid phase separation and optimize the heat stored in the supercooled SAT. It was found that composites of SAT with thickening agents or liquid polymers had the highest heat content of the investigated additives.

Investigations of SAT composites with extra water, thickening agents and graphite elucidated the thermal conductivity and the solidification behavior in bulk size samples. It was found that thickening agents had an effect on where cavities were formed during the solidification and cooling and the associated contraction of the PCM. Graphite flakes showed to have better effect on increasing thermal conductivity in SAT composites compared to graphite powder. The amount of thickening agents required to keep the graphite suspended and evenly distributed in the SAT composite was also elucidated.

Overall, the research has shown that it is possible to utilize stable supercooling of SAT for seasonal heat storage in actual application sized units. Furthermore, investigations have elucidated the potential for increasing the performance of a storage by using SAT composites with additives.