THERMAL BATTERIES

Storing heat allows you to produce and consume in your own time and at your own pace. The most common thermal store is an insulated water tank, and water can store a lot of heat for a given weight and volume.

S*pecific heat* is the energy required to raise the temperature of one cubic centimetre of a substance by one degree C. The specific heat of water is about 4.2 joules per degree C per cubic centimetre, which compares favourably with most other readily available materials.

Our hot water tank holds 200 litres (200,000 cc) of water which at the end of a long sunny day will have been heated by our solar thermal system to 70 degrees. Assuming our cold water supply is a consistent 10 degrees C, the energy required to raise 200 litres of water from 10 degrees to 70 degrees is 60 (that's 70 minus 10) times 200,000 (the number of cc's in the tank) times 4.2 (the specific heat of water). 60 x 200,000 x 4.2 = 50,400,000 joules, which means our tank holds just under 14kWh of heat when full of 70 degree water.

Although covered in thick Styrofoam the tank cools down over time (which is fine because that keeps our airing cupboard warm). The loss, which depends on the surface area of the tank and the insulation or "U" value of the Styrofoam, means that at 70 degrees we lose about 1.9 kWh of heat a day.

The specific heat of clay brick, on the other hand, is a meagre 0.2 joules/degree/cc, and while brick is denser than water, water can still hold over twice as much heat as the same weight of brick, heated to the same temperature. Yet night storage heaters and electric AGAs store heat in clay bricks rather than water. This is because you can heat brick to several hundred degrees C, while at atmospheric pressure water turns into steam at 100 degrees and thereafter becomes very expensive to contain.

For this reason, a brick heated to 600 degrees can store a lot more energy than the same weight of water, and in half the space. For example, a large night storage heater weighing 144kg, holds about 24kWh of heat when fully charged. Our water tank, which weighs over 200kg, only holds 14kWh when charged to its maximum safe temperature of 70 degrees. Even if we heated it to 90 degrees (which would require a more expensive high pressure tank) it would hold only 19kWh, and need a room of its own.

The fact that water turns to steam at 100 degrees highlights a property of materials that limits their utility, but which we can also exploit, for heat storage. Water is found in our environment in all three of its states – solid (ice), liquid (water) and gas (steam). Since we ourselves are largely liquid water, we tend to work best in the liquid temperature range of water, and need to protect ourselves from anything hotter or colder than liquid water.

Turning ice into water requires much more heat than it takes just to raise that amount of water by the same temperature. This additional heat energy is called the *latent heat* of melting. The latent heat of water is 334 joules per gramme (or cc) which is nearly 80 times its *specific* heat of only 4.2. So, while it takes 754,000 joules to boil a litre of frozen water, 334,000 of them are needed just to melt the water! Storing heat energy as latent heat is therefore much more weight and volume efficient.

Just as it takes a lot of energy to convert something from solid to liquid at the same temperature, re-freezing releases a lot more energy than normal cooling. This is a difficult effect for us to exploit with water, because we ourselves are much hotter than water in its solid state (ice). So while water turning into ice does indeed produce heat, it isn't much use to us. Ice is a useful way to store "cold", because it takes a lot of heat to melt it, but ice isn't something we normally use to store heat. It would be a different matter if water froze at, say, 45 degrees, because ice would then be hotter than we are, and the process of freezing would heat us up!

There are liquids that freeze at a higher temperature than water. And while anything hotter than our body temperature can be used to heat us up as it cools, a liquid crystallising at a higher temperature than ours will heat us up much more.

A well-known liquid of this type is the saturated solution of sodium acetate used in hand warmers (pictured below). It has a very useful additional property that makes it especially useful for this application. Unlike water, saturated sodium acetate will remain in a liquid state below its normal freezing temperature and does not freeze spontaneously unless some external factor induces it to crystallise.

In the hand warmer above crystallisation is induced by flexing a metal disc that produces tiny metal particles. This intervention is enough to cause "nucleation" which sodium acetate in its normal state requires in order to crystallise. As it does so, the hand warmer becomes hot to touch until all its latent heat is given up and the solution has largely solidified. This produces enough heat to warm your hands for several minutes, after which the sodium acetate will be largely solidified.

The solution can be melted again by heating it beyond its melting point. This takes about 5 minutes, after which the hand warmer will have re-liquidised, and after cooling down to room temperature will be ready to warm your hands again on demand. It is now storing the heat you used to melt it, but at room temperature.

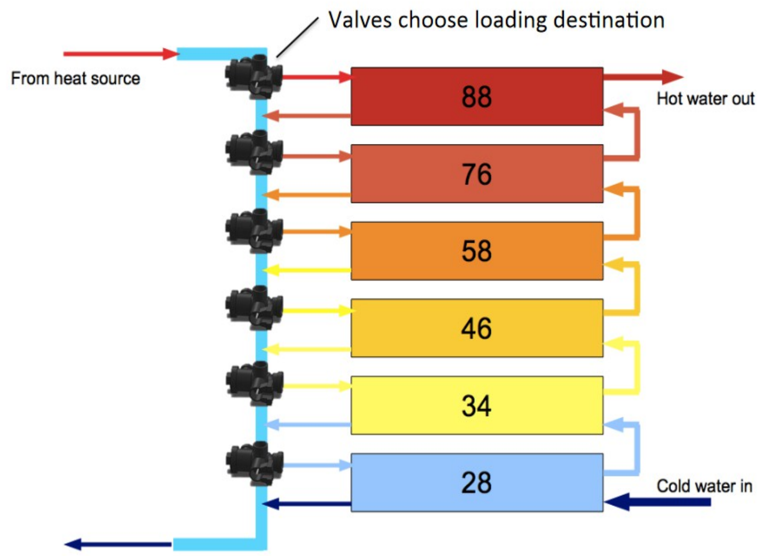
Saturated sodium acetate solution at room temperature is called a metastable or "supercooled" liquid, because it stoys liquid below its freezing point until crystallisation is externally induced. Its latent heat of melting (or crystallisation) is about 260 joules per cc - not quite as good as ice, but still over 60 times the specific heat of water, and occurring at a useful temperature of 58 degrees. Although its specific heat is much lower than pure water, the solution can also be used as a regular heat store by heating it well beyond its melting point. It boils at 120 degrees.

SunAmp is a thermal battery manufacturer that uses sodium acetate and other saline solutions to store heat largely, but not entirely, as *latent* heat. The battery consists of a sequence of insulated "cells" kept hot. They do not exploit the "metastable" property of the hand warmer solution. Instead, they are allowed to cool during discharge until they reach their natural crystallisation temperature at which point they give up their massive latent heat.

SunAmp battery cells are linked together in two water circuits - a closed circuit for "charging" the battery with hot water and an open circuit for heating cold water. The open circuit has a cold water mixing valve at the battery outlet to regulate the hot water to a fixed temperature of up to 65 degrees.

The mechanics of SunAmp's batteries are protected by patent, but we understand that as cold water passes through each cell it cools the hot solution, warming up in the process, until the first cell reaches its freezing point. There will then be a massive increase in heat output as the solution gives up its latent heat. The hotter water entering later cells will consequently be above their freezing temperature reducing the amount by which they are cooled. But as earlier cells are exhausted of their latent heat, they do not heat the incoming cold water by as much. This progressively increases the rate of cooling on later cells until they, too, give up their latent heat. This process continues until all the cells in the battery are exhausted of both their latent and specific heat.

This is shown in schematic form here:



The charging "circuit" on the left is used to selectively heat up individual cells. The stack is shown here in a half-discharged state where the lower three cells have already crystallised.

Using this modular technique, Sunamp currently offer three products with different numbers of cells and different charging methods:

1. SunAmpPV - this is designed to take excess solar PV electrical output which is used to charge a relatively small battery to between 5 and 6 kWh of heat, delivered as hot water at up to 65 degrees. It isn't designed to replace all your hot water heating, but simply to minimise your use of other heat sources. It acts as a thermal buffer and occupies far less space than an insulated water tank of the same thermal capacity.

2. SunAmpStack - this is designed to store the entire daily heat energy requirement of a large house. It is charged by hot water from a heating source such as a biomass heater or heat pump, enabling the heat source to operate at optimum rate and time. It stores up to 60kWh of heat energy.

3. SunAmpCube - this is configurable using arbitrary numbers of SunAmp thermal cells and is designed to store, as heat, the output of any large renewable generator such as a wind-turbine, hydro, or large solar array. It could be used as a dump load for grid-constrained renewable energy, which is a particularly promising market given the constraints imposed by Distribution Network Operators who are not always able to absorb significant additional output. This product is customised for each application, but would need a significant heat consumer such as a district heating scheme, large office premises or leisure complex with heavy hot water demand. A SunampCube can store up to 250kWh of heat energy.

Heat accounts for at least three quarters of our energy use, and heat at water temperatures makes up a significant proportion of that. As part of a wholesale transition to renewable energy generation, including everything from electricity to biomass combustion, thermal batteries can play as significant a role as electrical batteries and electrical storage in general. The nice thing about SunAmp batteries is that they are relatively easy to explain and incorporate into domestic and industrial space and water heating applications. They are, after all, just very compact hot water tanks.