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EFFICIENT ENERGY STORAGE IN PCM SOLAR TANK

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Abstract
The one of the most important part of a solar collector system is the solar tank. The relevant type and capacity of the solar tank is a requirement of the good operation of the system.
It is necessary to apply a solar tank because the period of the sunshine does not coincide with the time of the hot water consumption generally. The solar collectors work daytime only, and its power depends on the weather. The hot water consumption in family houses is generally bigger in the evening and in the morning, so it is necessary to store the utilized energy. The collectors transform but not store the solar energy. The storage is necessary to accomplish in a heat-insulated tank, placed in tempered space.
According the current architectural tendencies the boiler rooms are smaller, so the putting of the currently available solar tanks is very difficult. It is necessary to store the energy in a little space. The solution of the problem is the solar tank particularly filled with phase change material. This tank has smaller dimensions and bigger heat capacity than the conventional tanks.

1. INTRODUCTION

The temporal difference of energy source and energy needs made necessary the development of storage systems. *Except in summer, specially in winter, the temperature of the heat transfer fluid coming from the collector is relatively low (35-60 °C). In this period of time, one way of storage is to use solid-liquid phase change materials. In comparatively small volume the phase change materials have great storage capacity in small temperature interval.* [1] *Adding PCM (phase change material) modules at the top of the water tank would give the system a higher storage density and compensate heat loss in the top layer because of the latent heat of PCM* [2].

There are only a few type of PCM (phase change material) solar tanks are available in commerce. There are not any manufacturers or customers in Hungary. The PCM tanks have two groups by the construction:

- PCM tanks with inner core,
- PCM tanks with inner balls.

The benefit of the tanks supplied with the inner core is the easy putting of the phase change material. It is necessary to mention that the inner core is only in the upper half of the container, and the surface of the core is small. The phase change materials have small coefficient of thermal conductivity, so if the core has too big diameter the process of the melting and the solidification will be slow by the thicker and thicker solid layer on the inner surface of the core.

In the other type of the tanks the balls are filled with the phase change material. The diameter of the balls is very small for the diameter of the tank. The balls are not fixed to the tank. It results a bigger heat exchange surface area between the water and the phase change material. The other benefit of this form is that the heat transmission starts from all directions because the water surrounds the balls. The small diameter abates the unbeneficial insulating effect of the solid phase change material. The biggest disadvantage of this construction is the requirement special devices for making, filling and closing of the balls.

Our goal was to combine the advantages of the two different constructions. Additionally the easy manufacturing and the using of adaptable but not expensive materials was important too.

2. PHASE CHANGE MATERIALS

These materials can store energy by the melting at a constant temperature. No material has all the optimal characteristics for a PCM, and the selection of a PCM for a given application requires careful consideration of the properties of various substances. Over 20,000 compounds and/or mixtures have been considered in PCM, including single-component systems, congruent mixtures, *eutectics and peritectics* [3]. *The isothermal operating characteristics (i.e. charging/discharging heat at a nearly constant temperature) during the solidification and melting processes, which is desirable for efficient operation of thermal systems* [9].

One of the most important aspects during the selecting of the material is the conformable melting point and the high latent heat of fusion. The choice of the substances used largely depends upon the temperature level of the application [8]. *Residential, commercial and industrial buildings often have hot water requirements at around 60 °C and bathing, laundry and cleaning operations in the domestic sector generally need it at about 50 °C* [4]. The right melting point enables that the phase changing comes off during every usage cycle. Thereby the latent heat could be fully utilized. According to the required temperature of the domestic hot water the melting point should be between 40 and 50 °C. Out of accordance with the conventional solar tanks the temperature of the accumulation of heat is constant. *Storage systems using these heat accumulator materials can store the energy from the solar collector at lower temperature level, too in winter. The stored energy can be used for pre-heating the cold incoming water* [5].

The value of the latent heat is very important, because the higher latent heat results higher storable heat quantity. According these aspects we can choose from several materials (Fig. 1). We have to mind the chemical properties, the thermal expansion and the aspects of safety.

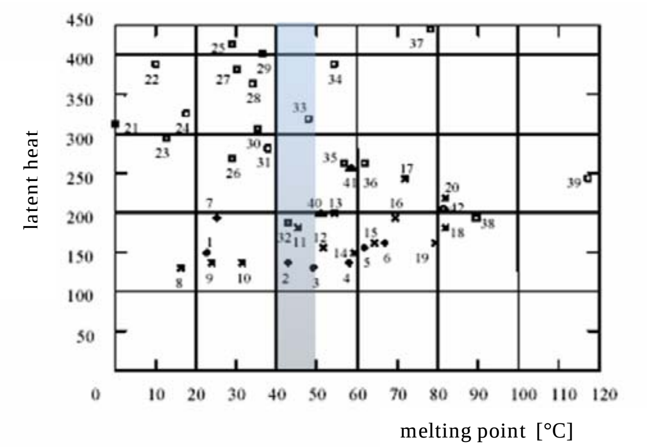

Figure 1. Latent heat of phase change materials in function of melting point [6] (1-7: paraffins, 8-20: organic compounds, 21-39: inorganic compounds)

PCMs in the 50 to 100 °C temperature range have been proposed to water heating and off-peak electrical heater applications.

The inorganic compounds have the highest latent heat, but these materials are disposed to under-cooling, so the phase changing do not come off in the melting point in every case. We can not use the latent heat if the material stay in liquid phase during the discharging method. It is not possible to choose these materials, because our goal is to utilize the releasing latent heat during the solidify.

The next group of the phase change materials is the organic compounds (but not paraffin). These materials are expensive and toxic acids. Normally there is not any contact between the water and the PCM, but in case of failure the PCM could mix with the water, so we must not apply toxic materials.

The last group is the paraffin'. These materials are suitable by the physical and chemical properties. The paraffins are obtainable at low price. These materials have only one disadvantageous property: flammability. In this case we have not mind this because the presence of the water around the tubes of the paraffins. Our chosen phase change material is the paraffin 5838:

Table 1. Physical properties of Paraffin 5838

melting-point	50°C
latent heat	145 kJ/kg
viscosity	1,9 mm²/s
density	1,412 g/cm³
specific heat capacity – solid	2,1 kJ/kgK
specific heat capacity – liquid	2,4kJ/kgK
coefficient of thermal conduction – solid	0,2W/mK
coefficient of thermal conduction – liquid	0,15W/mK

The paraffins are waxes at room-temperature. These are hydrocarbons. Increasing the number of C-atoms increases the melting point too. *The normal paraffins of type C_nH_{2n+2} are a family of saturated hydrocarbons with very similar properties. Paraffins between C_5 and C_{15} are liquids, and the rest are waxy solids. Paraffin wax is the most commonly used commercial organic heat storage PCM* [10]. *Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require large surface area* [10].

4. OWN CONCEPTIONAL MODELS

In addition to the combining the advantages of the two available constructions is important to mind the easy manufacturing. We have to apply available materials and keep down the costs. We have made three conceptional models (Fig. 2).

The first version has inner balls, filled with the PCM. It has the best heat transfer properties.

The manufacturing of this tank has three sections. The first one is the making of the tank, the second is the making of the solar heat exchanger, the third is the making of the balls, filled with phase

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change material. There are not problems with the first section, because the tank is similar to the conventional domestic hot water tanks. The solar exchanger is a conventional copper tube spiral. It could be manufactured easily. The main problem is the making of the balls. It requires special plastic moulding machine. The balls should be drilled and filled with PCM, and then we have to close the hole with welding. It is important to choose the right material for the balls. It has to resist the operating pressure and temperature.

The second model has an inner core. The main advantage of this model is the easy producing. It contains three sections too. The first and second section are similar to the first conception with the balls. The last phase is the making of the inner core. This method is similar to the making of the outer tank, the dimensions are smaller. The inner tank is made of corrosion-resistant steel because of the corrosivity of the water around this inner tank. The corrosion-resistant coating debases the transfer of heat. Because of the big size and the low coefficient of thermal conduction of the PCM the melting and solidifying are very slow.

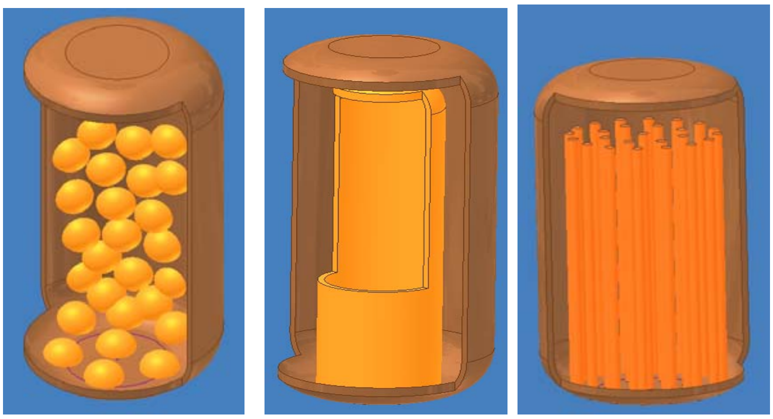

Figure 2. PCM solar tank provided with balls, inner core and tubes

The third model – the tank with inner tubes – combines the advantages of the first and the second model: it has large surface for the quicker heat transfer, and it could be manufactured easily.

The material of the inner tubes has to resist the corrosivity of the water. The tubes should be mounted to two discs. The diameters of the discs are similar to the inner diameter of the tank. The discs have holes to place the tubes. The lower ends of the tubes are closed with welding, the upper ends have threaded cover nut. This model has the lowest cost and the biggest surface for the heat transfer. According to these advantages we choose to design the third model.

The tubes are made of corrosion-resistant steel. The thin walls of the tubes result a very good heat transfer. The tank has 25 tubes with 60 mm outer diameter. Figure 3 shows the arrangement of the tubes and the solar heat exchanger spiral.

Figure 3. Arrangement of the tubes filled with paraffin and the solar heat exchanger

6. CALCULATION OF THE SOLIDIFICATION

The main problem of the operating of the PCM tanks is the low coefficient of thermal conductivity of the phase change material. During the discharging of the tank the PCM solidifies to the inner surface of the tube. The thermal flux will be decreased by the thermal insulating effect of the thicker and thicker solid PCM layer. I have calculated the required time of the solidification of the paraffin.

The equation of the thermal conductivity in tubes with two layers (layer 1 is the solid phase of the paraffin, layer 2 is the wall of the tube):

$$\Phi = \frac{2\pi h\left(t_{w3} - t_{w1}\right)}{\dfrac{1}{\lambda_{PCM}}\ln\dfrac{d_2}{d_1} + \dfrac{1}{\lambda_w}\ln\dfrac{d_3}{d_2}}$$

λ_{PCM} - coefficient of thermal conductivity of the paraffin
λ_w- coefficient of thermal conductivity of the tube
d_1- inner diameter of the solid paraffin layer on the inner surface of the tube
d_2- inner diameter of the tube
d_3- outer diameter of the tube
t_{w1}- temperature of the phase change
t_{w3}- temperature of the outer surface of the tube

During the solidification the value of d_1 decreases from d_2 to 0. The t_{w3}-t_{w1} temperature difference depends on the temperature of the water in the tank. With the equation we can calculate the required time of the solidification. The next diagram shows the decrease of the $r_1=d_1/2$ inner radius of the solid phase in function of time. The parameters are according to 60 mm tube diameter, 1 mm wall thickness, the PCM is paraffin, the material of the tube is stainless steel. The difference between the phase change temperature and the temperature of the outer wall of the tube is 2 °C.

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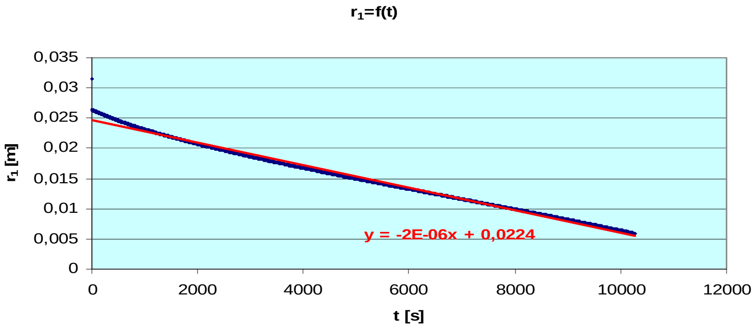

Figure 3. The decrease of the r_1 radius on the boundary of the liquid and solid phase in function of time, during the solidification

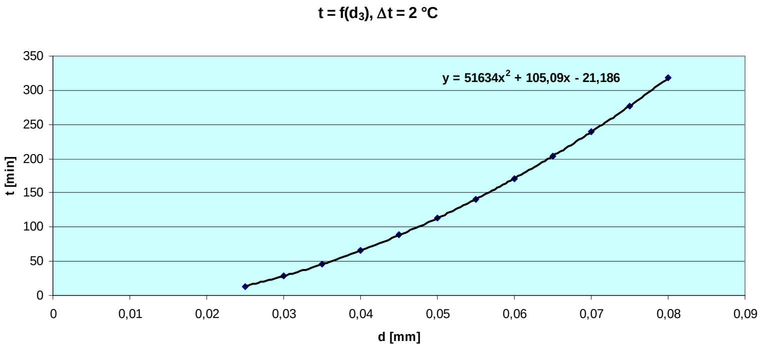

Figure 4. Time of the solidification in function of the tube diameter

The calculated time of the solidification is 172 minutes. Choosing 40 mm tube diameter instead of 60 mm the solidification time decreases to 66 minutes. The next diagram shows the time of the solidification in function of the diameter of the tube.

The same amount of the PCM requires more tubes if the diameter is smaller. The specific heat exchange surface is greater, the solidification is quicker, but the volume of the material of the tubes is greater too, so the heat capacity of the solar tank is lower. The above functions are definable according to the physical properties of the phase change material and the difference between the phase change temperature and the temperature of the outer surface of the tube. We can calculate the maximal tube diameter for a required phase changing time. With these functions we can calculate the ideal parameters for a definite system and operating.

7. SUMMARY

Tank proposed by us with inner tubes combines the advantages of the existing types of tanks. These inner tubes are filled with the PCM. The material of the tubes has to resist the corrosive effect of the water. The tubes are in a holder which has equal diameter with the tank. This holder keeps the tubes to equal distances. The lower ends of the tubes are closed with a welded ending, the upper ends have threaded cap. This is a simply configuration with large heat exchange surface area.

The cost of the manufacturing of the tank is lower than the conventional tanks in trade with the same heat capacity and the space demand is much lower too. The other advantage of the PCM tank is the constant temperature during the heat accumulation. This constant temperature could be lower, it depends on the type of the PCM. The lower temperature of the heat accumulation permits the higher efficiency of the collectors at low external temperature. These facts show the adaptability of the conception.

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