DESIGN OF AN EXPERIMENTAL 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.

A solar tank particularly filled with phase change material has smaller dimensions and bigger heat capacity than the conventional tanks.

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.

We have calculated the time of the phase changing and the operating temperature of the heat accumulating. If the temperature is lower than the conventional tanks it could result a higher efficiency of the solar collector system. We have made pre-calculations to study this possibility.

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].

This construction has big heat exchanging surface, and the manufacturing is simple.

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 [4].
The paraffins 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 first 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 [5].
Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require large surface area [5].

3. OWN CONCEPTIONAL MODELS

In addition to the combining the advantages of the available constructions is important to mind the easy manufacturing. We have to apply available materials and keep down the costs.

The tank with inner tubes – combines the advantages: 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:

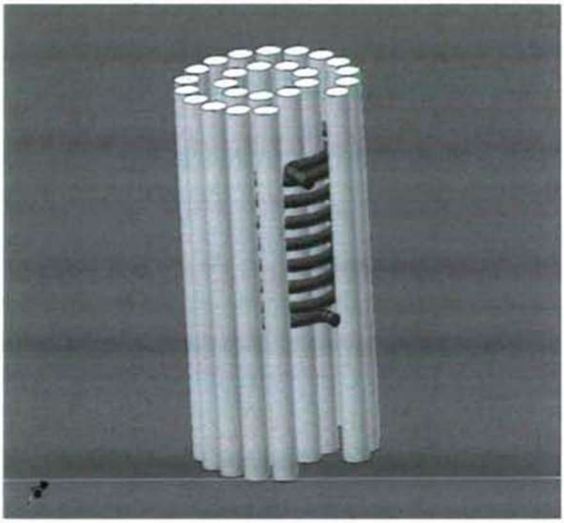

Figure 1. Arrangement of the tubes filled with paraffin and the solar heat exchanger

4. 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):

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

Legend:

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:

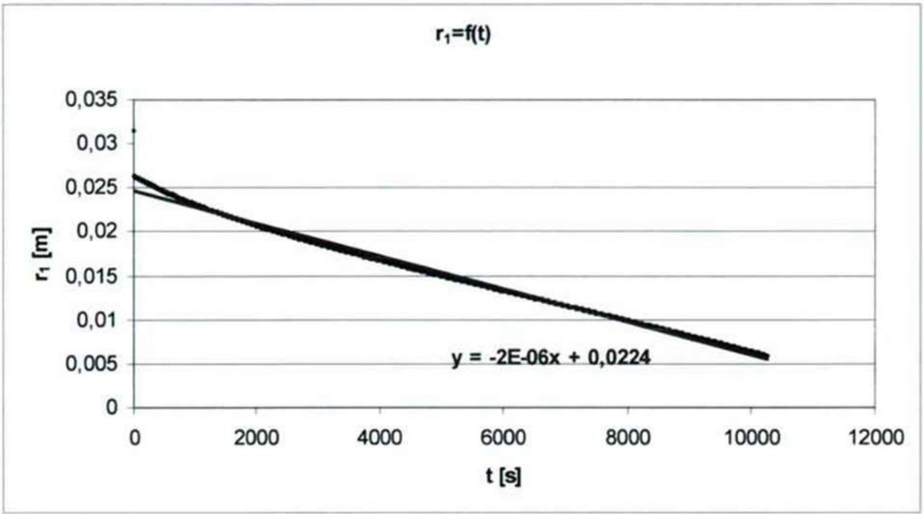

Figure 2. The decrease of the r_1 radius on the boundary of the liquid and solid phase in function of time, during the solidification

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:

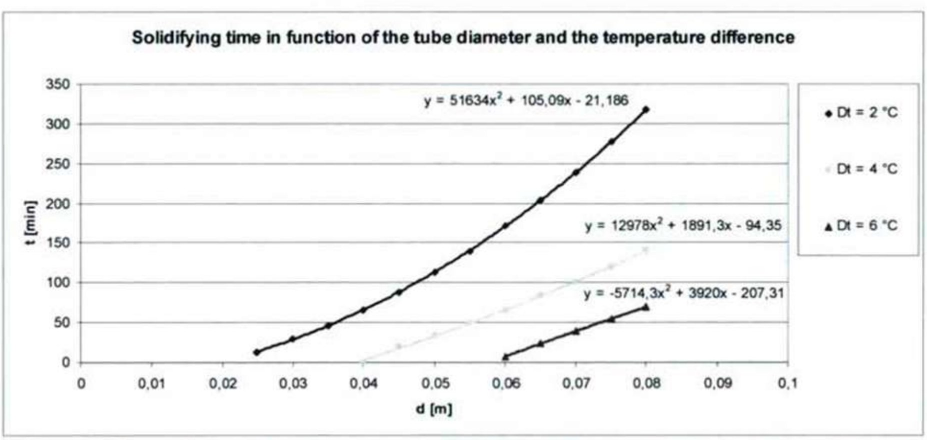

Figure 3. Time of the solidification in function of the tube diameter and the temperature difference between the PCM and the outer wall of the tube

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.

5. OPERATING AT LOWER TEMPERATURE

The lower difference between the temperature of the collector and the outer air results higher solar collector efficiency.

The paraffin has smaller specific heat capacity than the water, so it results higher temperature in the PCM-tank, than the conventional solar tank in a summer day:

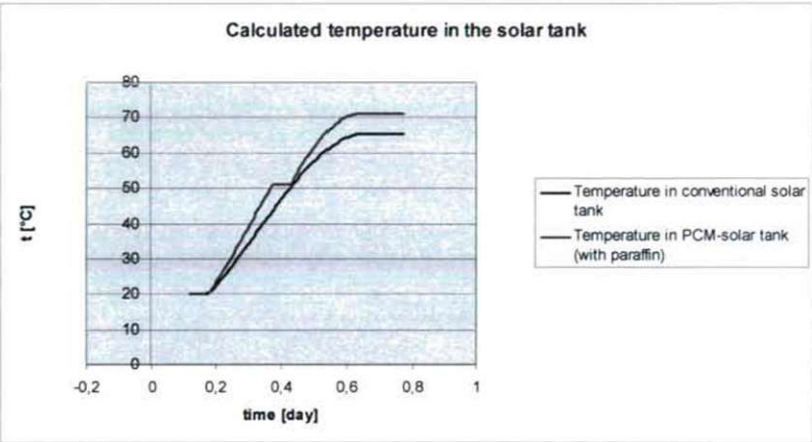

Figure 4. Comparing the temperature in a conventional solar tank and a PCM-tank with paraffin

The diagram above shows the result of a calculation of a PCM-tank with 70 kg water around the tubes and 170 kg paraffin in the tubes. We used for the calculation the efficiency characteristic of our own-designed experimental flat collectors.

The temperature of the PCM-tank is higher than the conventional because of the lower heat capacity of the PCM, so the collectors has to operate at higher temperature, and the efficiency is lower because of the heat loss from the collector to the air. If our goal is the higher efficiency we have to choose another PCM with lower melting point.

In our every calculations the same weather conditions result higher efficiency with the conventional tanks, so the main advantage of the PCM-tanks is the lower space demand.

6. 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.

The lower heat capacity of the PCM could result higher temperature in the solar tank, so the higher collector temperature results lower collector efficiency. With our PCM-tank we can test different phase change materials to calculate the efficiency.

REFERENCES

1. Lovász A; Bajnóczy G; Gagyi-Pálffy E; Prépostffy E.: Domestic Hot Water Pre-heater Utilizing Solar Energy. Periodica Polytechnica Chem.Eng. 50/1 45-53. 2006.
2. Muhsin Mazman, Luisa F. Cabeza, Harald Mehling, Miquel Nogues, Hunay Evliya, Halime Ö. Paksoy: Utilization of phase change materials in solar domestic hot water systems. Renewable Energy 34 (2009) 1639–1643
3. Dinçer I, Rosen MA.: Thermal energy storage, systems and applications. Chichester (England): John Wiley and Sons; 2002. ISBN 0-471-49573-5
4. Mithat Akgün, Orhan Aydın, Kamil Kaygusuz: Experimental study on melting/solidification characteristics of a paraffin as PCM. Energy Conversion and Management 48 (2007) 669–678
5. Garg HP, Mullick SC, Bhargava AK.: Solar thermal energy storage. Dordecht: D. Reidel Publishing Company; 1985. ISBN 90-277-1930-6