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DOMESTIC HOT WATER PRE-HEATER UTITLIZING SOLAR ENERGY

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Abstract

A two grade phase change material (PCM) based on $CaCl_2$-water system has been investigated in a PCM stuffed copper tube-water heat exchanger. The heat output of the two grades has been measured in exhausting cycle. The heat storage system is to be applied to store solar energy and the stored heat is used to preheat the water input of domestic hot water supply system.

Keywords: phase change material, solar collector, heat exchanger, calcium chloride.

1. Introduction

As a consequence of Hungary's joining to the European Union we must assign an increasing part to renewable energy sources in our energy consumption. From the nature of the country biomass utilization, geothermic energy consumption can cause breakthrough, beside these we can not give up the consumption of other energy sources such as wind and solar energy.

Relating solar energy often emerges an estimated value: the amount of the incoming energy is approximately 15000 times greater than the annual energy need of the Earth. Although these numbers are quite misleading, this quantity is converted into given purposes (30% reflects, 47% heats, 23% hydro geological cycle, less than 1% of the energy is used by photosynthesis, which is only a rounding off). The other limit of solar energy utilization is the relatively small surface energy density.

The energy arriving from the Sun reaches upper fields of the Earth's atmosphere with approximately constant radiation power. Nowdays the accepted value of solar power is approximately $1353 \mathrm{W/m^2}$ (solar constant).

Table 1 gives information about the Hungarian Solar Energy Radiation [1].

From the facts of *Table 1* it can be seen that there is a great difference between the specific value of radiation in wintertime and in summertime. What is this radiation energy sufficient for? If we concern the heat consumption, the necessary heat energy is 250 $\mathrm{kWh/(m^2 \cdot 6month)}$ in respect of living space and heating season. Which is almost $\mathrm{1kWh/(m^2\ day)}$. It means a flat should have been equipped with a same sized collector. But it can assure the needful heat if the sun is shining.

Table 1. Average solar energy radiation in Hungary [1]

Month	January	July
Incoming radiation	1.5 kWh/(m^2day)	5.0 kWh/(m^2day)
Utilizable radiation	1.1 kWh/(m^2day)	2.8 kWh/(m^2day)

It is much better if we talk about domestic hot water supply. Take a household with four people as a basis: the energy needs of hot water production is 14kWh/day for 200 dm^3 hot water of 60°C. The desired energy can be collected easily during the summer, with correspondingly sized collector and it is not a problem during wintertime too.

2. Producing Hot-water with Solar Collector Systems

The temporal difference of energy source and energy needs made necessary the development of storage systems. The abundant amount of solar energy, which is collected during the summer, could be stored in such a big storage unit, engineering and economic requirement of which are disproportional. Systems which equalize the temporal difference in one or two days, can be economic. In summer the energy of the heat transfer fluid arriving from the solar collector at relatively high temperature (70°C-90°C) can be stored in insulated hot-water container.

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 which means nine months in a year, 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. Storage systems using this heat accumulator materials can store the energy from the solar collector at lower temperature level in winter. The stored energy can be used for pre-heating the cold incoming water, so in the households the unit which is actually producing hot-water (gas or electric boiler) is supported by the unit storing solar energy. So the traditional system integrated with solar energy storage might moderate the cost of the energy consumption.

3. Phase Change Materials as Heat Accumulatos

In practice several phase change materials (PCM) are known, such as: paraffins, fatty-acids, organic and inorganic salt hydrates, organic and inorganic eutectic compounds [2, 3]. Theoretically isotherm heat storage, in accordance with phase change temperature can be achieved by these materials.

Conditions of using phase change materials are: relatively high latent heat, high heat conductivity (more than 0.5 W/m° C), material's melting temperature should be in the functional interval (15°C < T < 90°C) if it stores solar energy, congruent melting, minimal supercooling, chemical stability, economic efficiency and aspects of environmental protection [4, 5, 6].

In the course of the experiments a special phase change material was examined that stored heat in two different temperature grade [7]. The grade which stores heat on lower temperature is isotherm (29 °C). The other links to higher temperature grade (29 – 42 °C), that can be considered a storage system with high apparent specific heat. The reason for the high apparent specific heat is the continuous crystallization of the PCM during the temperature drop and energy production in the interval mentioned above.

4. Heat Storage by two Grade Phase Change Material

The two grade phase change material, examined in a pre-heater that can be linked to the domestic hot-water system, is a solution containing 211.4 mol of $CaCl_2$/1000 mol H_2O. The way of heat storage process is shown on the phase diagram of $CaCl_2$ - H_2O (*Fig. 1*).

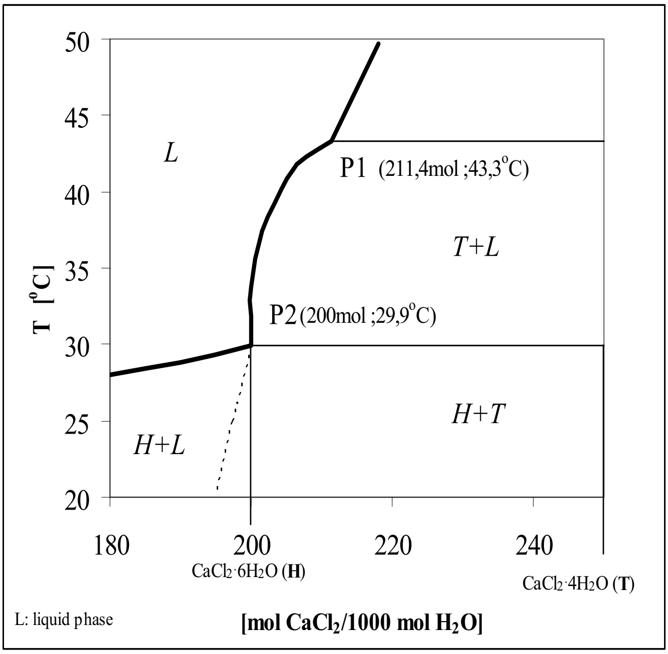

Fig. 1. Phase diagram section of the $CaCl_2$-water system

The two grades can be connected to two peritectic points $P1$ (211.4 mol $CaCl_2$/1000 mol H_2O ; 43.3°C) and $P2$(200 mol $CaCl_2$/1000 mol H_2O ; 29.9 °C).

If the phase change material is heated above the appropriate temperature ($P1$), the crystals melt. During the cooling the melt preserves the peritectic composition, until it reaches point $P1$. From this point the crystallization of $CaCl_2$ $4H_2O$ starts which causes the release of crystallization heat and goes on until the temperature reaches the temperature of point $P2$. During the phase change the temperature follows the liquidus line as a function of the amount of solidified $CaCl_2$ $4H_2O$ and gradually decreases to 29.9^oC. Continuing the heat extraction in the presence of seeding crystals ($SrCl_26H_2O$ and $Sr(OH)_2$ $8H_2O$) the rest of melt solidifies as $CaCl_2$ $6H_2O$.

The temperature remains constant during this process.

The heating part of the cycle involves the semicongruent melting of $CaCl_2$ $6H_2O$ and the peritectic melting of $CaCl_2$ $4H_2O$. The peritectic melting is accompanied by the segregation of solid $CaCl_2$ $2H_2O$. This solid material should be dissolved in the melted phase otherwise loss of heat storage capacity happens.

5. The Heat Exchanger Charged with Two Grade Phase Change Material

We examined the thermal properties of the heat storage tubes containing the two grade phase change material, in a heat exchanger special for this experiment. Water was the circulating agent among tubes, heat transfer was stagnant inside the tubes. The PCM was a solution of 211.4 mol $CaCl_2$/1000mol H_2O. It was situated in copper tubes (diameter 28 mm), which were placed horizontally in the heat exchanger.

Table 2 shows the parameters of the heat exchanger.

Table 2. Main parameters of the storage system containing two grade phase change material.

Outer dimensions:	450×450×515mm
Wall :	2 mm steel plate
Insulation:	15 mm plastic foam
Inner volume:	88.2 dm^3
Volume of heat transfer fluid inside the exchanger:	58 dm^3
Volume of the PCM:	12.6 dm^3
Number of the heat storage tubes:	18
Surface of the heat storage tubes:	3.28 m^2
Diameter of the tubes:	28 mm

The hot water coming from the solar collector was simulated by a flow through 21 kW electric boiler, which can be adjusted between 40°C-60°C transformation range. *Fig. 2* shows the diagramatic make-up of the experimental equipment. The

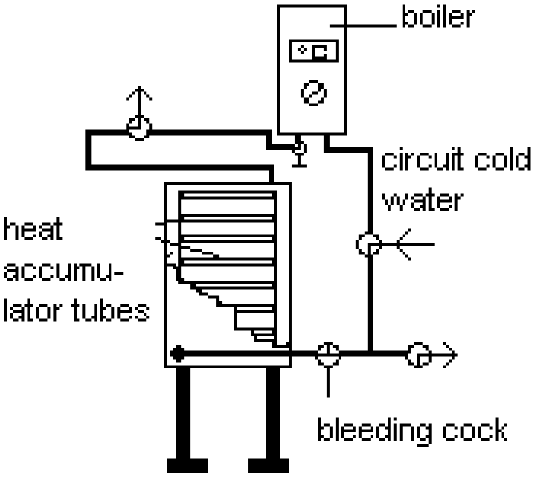

Fig. 2. The heat exchanger during the cooling of the heat accumulator tubes

heat exchanger did not contain the appropriate flow fences, so we avoided the channelling by using alternating hot and cold water input. The hot water having lower density streamed to the highest point of the heat exchanger, the cold water having higher density streamed to the bottom. The volume flow of the heat transfer fluid was 3.5 dm^3/minute. The temperature of the effluent and influent heat transfer fluid was recorded by thermometers connected to computer.

The tests were broadened to the corrosion property of the PCM situated in the copper tubes. We have assigned the potential difference between the copper tube and the solder in the case of air connected, melted PCM. And we have measured the corrodibility of the copper tubes in the case of dissolved oxygen and oxygen-free heat storage material.

6. Results

The accumulated heat by the two grade phase change material can be calculated by the given relation:

$$Q = \underbrace{M \cdot \left(\int_{T_{f1}}^{T_{initial}} c_{pl} dT + \int_{T_{f2}}^{T_{f1}} c_{p,virt.} \right)}_{I.grade} + \underbrace{\left(M_{CaCl_2 \cdot 6H_2O} \cdot \Delta H_f + M \cdot \int_{T_{final}}^{T_{f2}} c_{ps,average} dT \right)}_{II.grade}$$

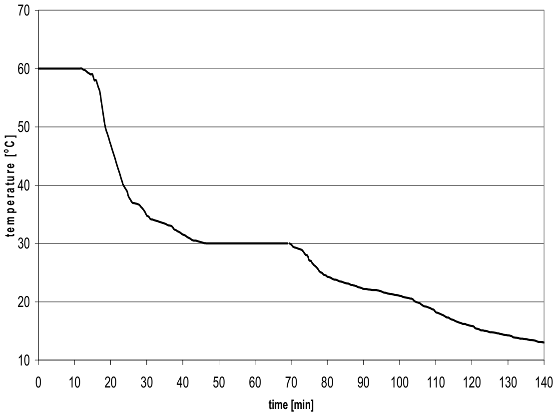

Fig. 3. Cooling curve of the two grade PCM measured by 30°C and 15°C water coolant

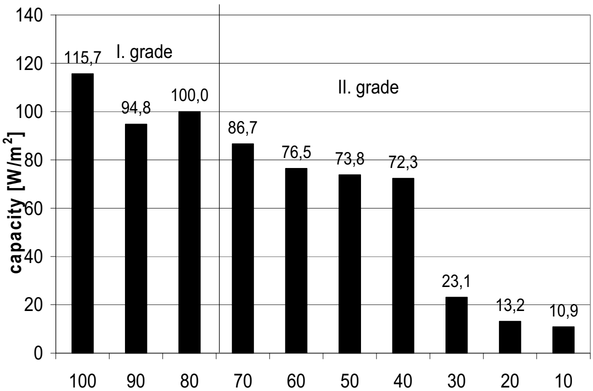

Fig. 4. Heat power of accumulator tubes based on cooling curve measured by 30° C and 15°C water coolant

where

$\mathbf{Q}$	storage capacity [kJ]
$\mathbf{T}_{f2}$	the start of crystallization of $CaCl_2$ $6H_2O$ (29.9 °C)
$\boldsymbol{M}$	mass of the phase change material [kg] in the second grade
$\mathbf{M}_{CaCl2.6H_2O}$	the mass of $CaCl_2$ $6H_2O$
$\mathbf{T}_{final}$	temperature of the PCM at the end of heat recovery solidified from 29.9 °C [kg]
$\mathbf{T}_{f1}$	the start of crystallization of $CaCl_2$ $4H_2O$ in the grade I. (43.3°C) in the range of $\mathbf{T}_{initial} - 43.3$°C
$\mathbf{c}_{pl}$	specific heat of fluid phase PCM 2.09 kJ/kg °C,
$\mathbf{T}_{initial}$	the temperature of the PCM at the beginning of heat recovery 11.5 kJ/kg °C (*the cooling of liquid phase is accompanied*
$\mathbf{c}_{p,virt}$	virtual specific heat in the interval of T_{f1} - T_{f2} $T_{initial} > T_{f1}$ *by partial crystallization*)
$\Delta \boldsymbol{H}_f$	phase change enthalpy of $CaCl_2$ $6H_2O$ =188 kJ/kg
$\mathbf{c}_{psaverage}$	specific heat of the solidified PCM 0.8 kJ/kg °C

Table 3 shows the ratio of the withdrawable and theoretically accumulated amount of heat.

Table 3. Theoretical and available storage capacity of the two grade phase change material

Grade	Temperature interval of accumulation	Theoretical storage capacity [kJ/dm^3]	Available storage capacity [kJ/dm^3]	Available storage capacity [%]
I.	60 °C – 30 °C	175	156	89
II.	30 °C – 12 °C	199	196	98
I + II	60 °C – 12 °C	374	352	94

Because of the small difference between the theoretical and the available storage capacity we could avoid the channelling, disabling heat recovery by the appropriate water input.

We have measured the relation of pre-heated water temperature and time during the period of heat recovery in two different ways; the storage capacity of the given grade was obtained by applying water being pre-heated on two different temperatures (30°C and 15°C) *(Fig. 3)*, otherwise we exhausted the heat capacity of the double grade by continuously applying water on 15°C (*Fig. 5*).

We have determined the heat power of the heat accumulator tubes from the cooling curve as a function of percental storage capacity ((*Figs. 4, 6*). Approximation of the percental storage capacity from the cooling curve was assumed constant heat loss.

The two grades can be well traced on *Fig. 6.* The crystallization of calcium-chloride-tetra-hydrate attended by a temperature drop and a power decrease can be observed on the heat accumulator tubes. During the isotherm grade the output

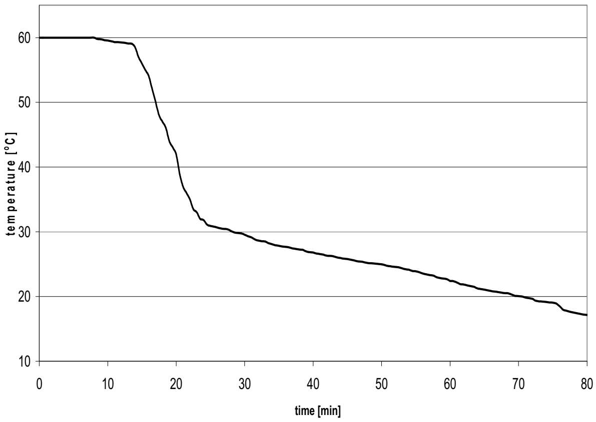

Fig. 5. Cooling curve of the two grade PCM measured by 15°C water coolant

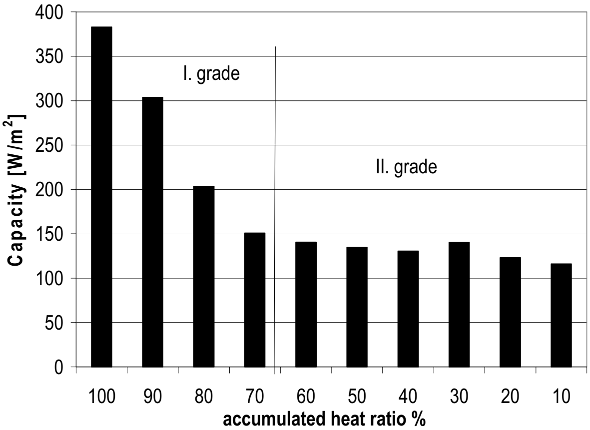

Fig. 6. Heat power of the accumulator tubes based on cooling curve measured by 15° C water coolant

slowly decreases (during the crystallization of $CaCl_2$ $6H_2O$). The cause of slower decrease is the formation of insulating layer from crystals deposited on the inside wall of the heat accumulator tubes.

Inorganic salt hydrates having peritectic melting character, as in $CaCl_2$ – water system (along advantageous properties) show a decrease in heat storage capacity after several storage cycles because of the segregation of phases during melting. The task of further experiments is to define this effect correctly, and to solve the problem of containment.

In accordance with the results of corrosion tests a number of decimal volt potential difference can be measured in the melted PCM between the copper and solder. The copper tube definitely indicates the signs of corrosion in the melted heat storage material with the presence of dissolved oxygen. However in the closed tubes the corrosion stopped after the running out of dissolved oxygen.

Acknowledgement

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