Heat-accumulation system powered by photovoltaic modules

Milena Goranova[1] and Bohos Aprahamian[2]

Abstract – **In this study a heating system working with Glauber's salt as heat-accumulation material is proposed. That is powered by renewable source - roof type photovoltaic (PV) generator. A design methodology for the system: PV generator - low temperature printed circuit board (PCB) heater - container with heat-accumulation material is proposed. A direct link between the generator and the heaters is used, since the characteristics of the system allow maximum use of the source. A complete laboratory experimental model, used for space heating, is presented.**

Keywords – **heat-accumulation, Glauber's salt, photovoltaic, PCB heater, Phase Change Materials - PCMs.**

I. Introduction

The properties of the materials with low melting temperature (so called Phase Change Materials - PCMs) and their application in the heating (or cooling) systems are a subject of concern in many research papers and patents [1, 2, 6, 7, 8, 9, 10]. The proposed systems in these sources are mainly based on direct use of solar radiation. Under the solar radiation impact the PCM reaches his melting temperature and some amount of heat is accumulated in it. Giving her through the night is used for space heating. Thus is used to build the passive houses (or so called solar houses) and new technologies for heating and insulation have been developed. The studied heating systems are designed and built for the construction of the buildings, as part of the premises. PCM is subjected to sunlight or a complex system of heat exchangers is used. This approach complicates the use of such systems in existing buildings which are not in accordance with the modern requirements for use of renewable energy. The aim of the paper is to propose a heating system operating through photovoltaic (PV) generator and low temperature printed circuit board (PCB) heaters. In this way the heating of PCM's heat storage material is not using solar radiation, but the electric power from a PV generator. Thus allows the use of the heating systems in existing buildings, without having their full reconstruction.

II. Analysis

To solve the task is designed, constructed and experimentally studied heat storage system with the following key elements:

- Steel, hermetically sealed containers with a parallelepiped shape (Figure 1., position 1) in which is placed the used PCM. In this case it is sodium sulfate decahydrate (Glauber's salt - $Na_2SO_4.10H_2O$).
- Flat, low PCB heaters located on the widest part of the container.
- Among these, a heat-conducting electrically insulating material is used, which is not shown in the figure.
- Roof type PV generators (Figure 2), with different structure and wiring scheme.

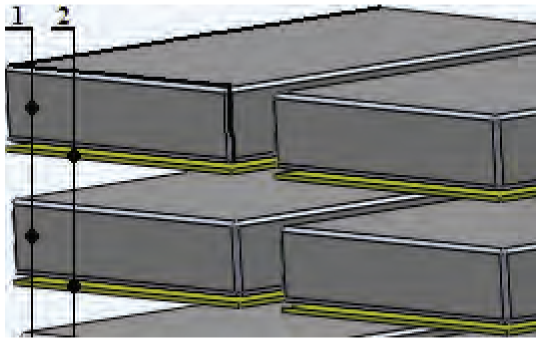

Figure 1. Construction of the heat storage system; 1 - containers with Glauber's salt; 2 - PCB heaters.

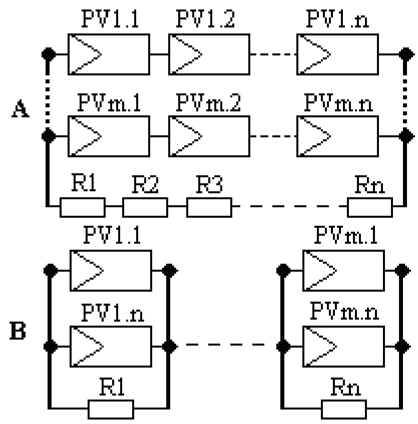

Figure 2. Wiring diagrams of the PV generators and heaters.

The direct connection between the heater and generator allows not to use converter, the goal is to obtain a low-cost system with fast payback. This requires the complex of parameters of the PV-PCB system to be dimensioned so as to ensure the maximum voltage and current, respectively, the maximum temperature of the heater with full power of the generator.

The steps in the design of the system are related to the dimensioning of his main three parts.

[1] Milena Goranova, PhD student, Technical University of Varna, Bulgaria, e-mail: milenagoranova@email.bg

[2] Bohos Aprahamian, Assoc. Professor, Technical University of Varna, Bulgaria, e-mail: bohos@abv.bg

A. Basic equations in the design of the heat storage system

The thermal energy stored in the Glauber's salt is determined by its specific heat capacity c_g, its mass m_g and its initial τ_o and final τ_n temperatures :

$$Q_{Gsalt} = c_g.m_g(\tau_n - \tau_o) = C_g.\theta \quad (1)$$

where:
C_g - heat capacity; θ - temperature difference.

The heat storage system is effective when it reaches full melting of the salt.

This allows storage of the latent heat c_{gl} of the molten salt.

The stored energy Q_{Gsalt2} in the melting process is expressed by the equation (2):

$$Q_{Gsalt2} = C_g.\theta + m_g.c_{gl} \quad (2)$$

The energy Q_{Gsalt2}, the heating time t_n and the installed power of the heaters P_n are bound by the equation:

$$P_n = \frac{Q_{Gsalt2}}{t_n} \quad (3)$$

The needed energy Q_{Gsalt2} have to comply with the volume of heated space.

The heating time t_n is averaged over time to daylight for a specific location.

The main characteristics of the Glauber's salt applied for determination of the parameters of the heating system are shown in Table 1.

TABLE I
MAIN CHARACTERISTICS OF THE GLAUBER'S SALT - $NA_2SO_4.10H_2O$

Molar mass	322,2 g/mol
Density	1,464 g/cm3
Melting point	32,38 oC
Heat of fusion	254 kJ/kg 377 MJ/m3
Thermal conductivity	0.544 W/m.K

B. Design of the PCB heaters

In the designing of the system we must take into account that the room is heated and during the melting period of the salt, through the heat transfer from the surface of the containers.

Both processes require enough installed capacity, which determines the total power of the heaters.

In this case, as an initial approximation, the resulting output of equation (3) is doubled.

The designing of the heaters was made according to [3.5] which deals with direct connection in the system PV generator – foil PCB heater.

The maximum temperature of the heater is 70oC to correspond to the temperature range of the systems with direct solar heating.

C. Designing of the PV generator

In the experimentally studied model, the generator is roof type, filled with modules of several architectures: mono-and polycrystalline, thin film.

The basic equations necessary for designing the PV generator are as follows [4]:

Minimum nominal voltage:

$$\mathrm{U}_{\min(\tau T)} = \mathrm{U}_{\mathrm{mpp(stc)}} + \left(\mathrm{T_u}.(\tau_T - \tau_{STC})\right) \quad (4)$$

where:
τт – temperature for calculations (module's temperature);
τstc – temperature of the module under standard testing conditions (25oC);
Umpp(stc) – voltage at maximum power for standard testing conditions;
Tu– temperature coefficient of the voltage.

Maximum nominal voltage:

$$\mathrm{U}_{\max(\tau T)} = \mathrm{U}_{\mathrm{mpp(stc)}} + \left(\mathrm{T_u}.(\tau_T - \tau_{STC})\right) \quad (5)$$

Maximum nominal current

$$I_{\max(\tau T)} = I_{\mathrm{mpp(stc)}} + \left(\mathrm{T_I}.(\tau_T - \tau_{STC})\right) \quad (6)$$

where:
Impp(stc) – nominal current at standard testing conditions;
TI – temperature coefficient of the current.

The described equations are specifying the structure of the generator: the number of series-connected modules in the string (PV1.1, PV1.2 ... PV1.n) and the number of strings in parallel.

Depending on the characteristics of the system it is possible that all the heaters can be connected in series (Figure 2. A) or each can be fed separately (Figure 2. B).

III. EXPERIMENTAL DATA

The experiments were conducted using experimental model applied to heat the living space. The measurements were made during the winter season 2012-2013 at ambient temperature - 1oC to +5oC.

Figure 3 shows the process of heating of the salt, as measured by a thermocouple placed in the container. The experimental model reaches the temperature of the salt melt for approximately 2 hours. The melting process continued for 5 hours at a maximum power of the PV generator. After the complete melting of the salt the temperature should increase. In this the molten salt is overheated, but as this process takes place in the late hours of the day at a small power of the generator, the overheating is not dangerous.

The cooling process of the molten salt is shown in Figure 4, graph 1. In order to compare, the same figure shows a typical cooling curve of material, in which no phase transition is reached, for example, water.

Figure 5 shows a record of the received power for several days. The group of curves in the sector 1 indicates days, which give a complete fusion of the salt. In curve 2 the resulting capacity is insufficient and the heating system works inefficiently.

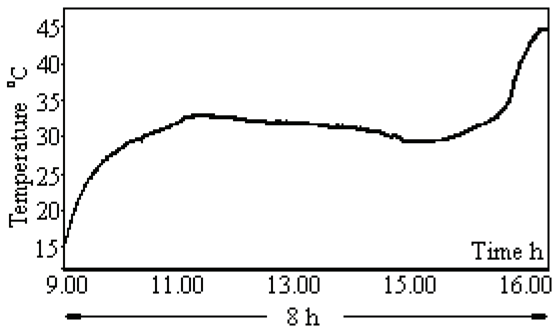

Figure 3. Transient heating process of the salt

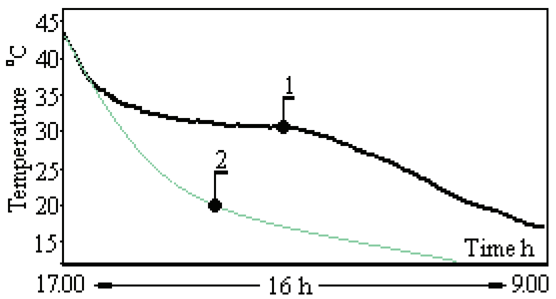

Figure 4. Transient cooling process:
1 - Glauber's salt; 2 - water.

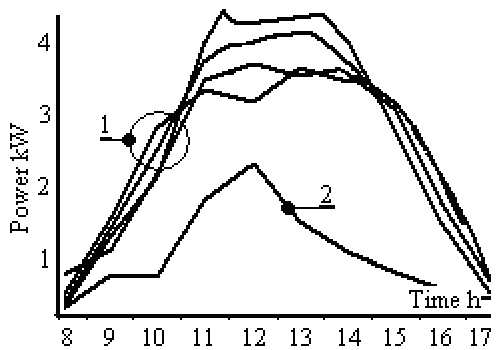

Figure 5. Power of the installed PV generator as a function of time of day

Figure 6 presents photo taken with IR camera of the heating system. The following positions are indicated: 1 - metal containers with Glauber's salt, 2 - PCB heater placed between the containers, 3 - electrically insulating, thermally conductive mica. The proposed construction allows uniform heating of the salt and achievement of the smelting process in the whole volume.

This is confirmed by the photo of Figure 7. A - temperature distribution on the surface of a heater placed on the containers.

The geometrical dimensions of the system container - heater are analyzed by the finite element method and simulation procedure.

Additional experiments were performed with a container in a cylindrical form and cylindrical (round) heaters, completely immersed in the salt.

The result is shown in Figure 6. B - during the heating the temperature is greatly unevenly distributed.

The volume around the heater overheats and melts, the remainder is cold, which is due to the low thermal conductivity of the salt.

IV. Conclusion

The studied heating system should reach full melting of the salt (Figure 3), in which the energy is accumulated according to equation (2).

As a result of the phase transition is obtained the cooling curve (Figure 4, graph 1), wherein the heating process is more efficient compared to the materials without a phase transition (Figure 4, graph 2).

The fundamental equations (1) - (6), and the studies in [3,5] allow the system PCB heater - PV generator to be designed so as to provide the desired temperature control of the heating.

The direct connection of the heaters and the generator without using converter reduces the investment cost and is shortening the repayment of the system.

On the other hand a converter would be useful as a voltage-adding power system through which shortages of power of the PV generator can be compensated (Figure 5, graph 2). The choice of using it complies with the specific requirements.

The system operates in a more stable connection to the scheme on Figure 1.B. as it is less dependent on the shading, contamination of the modules, changing the resistance of the heating element during the operation, etc.

The problem with this circuit is linked to the difficult wiring and therefore is used as a priority the scheme of Figure 1. A.

The proposed design ensures uniform heating of salt by uniform field across the PCB heater – Figure 7. A. Furthermore, the containers of parallelepiped shape can be mounted on the walls of the room without the loss of the space therein. The cylindrical structure of Figure 7. B. is not recommended.

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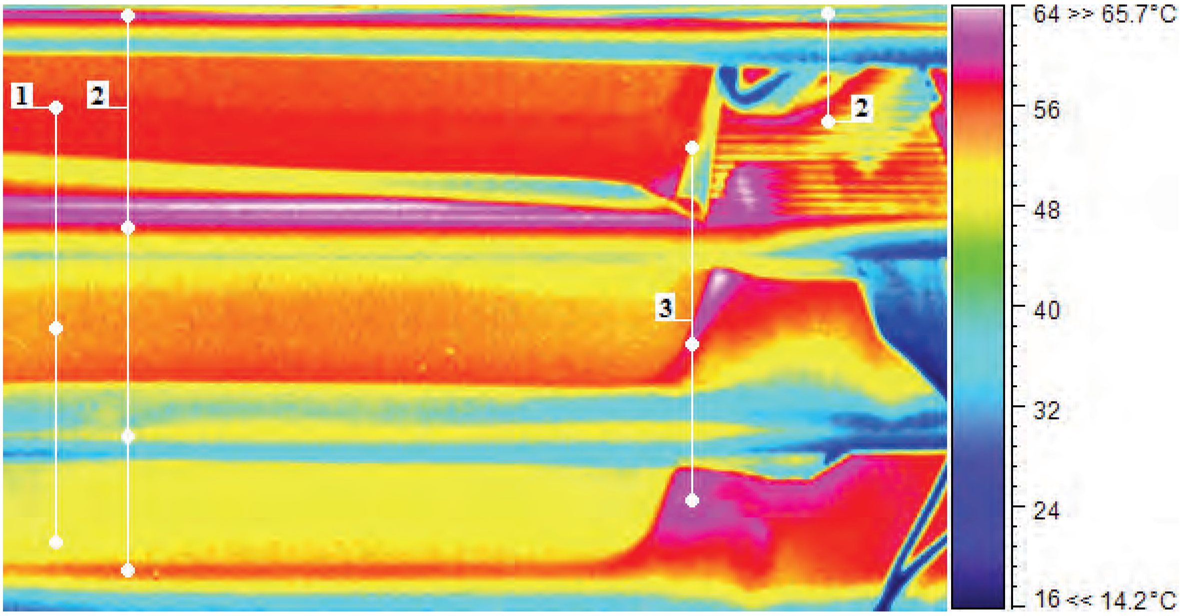

Figure 6. Photo of the heat storage system made with IR camera:
1 - containers with Glauber's salt, 2 - flat PCB heater, 3 - electrical insulation.

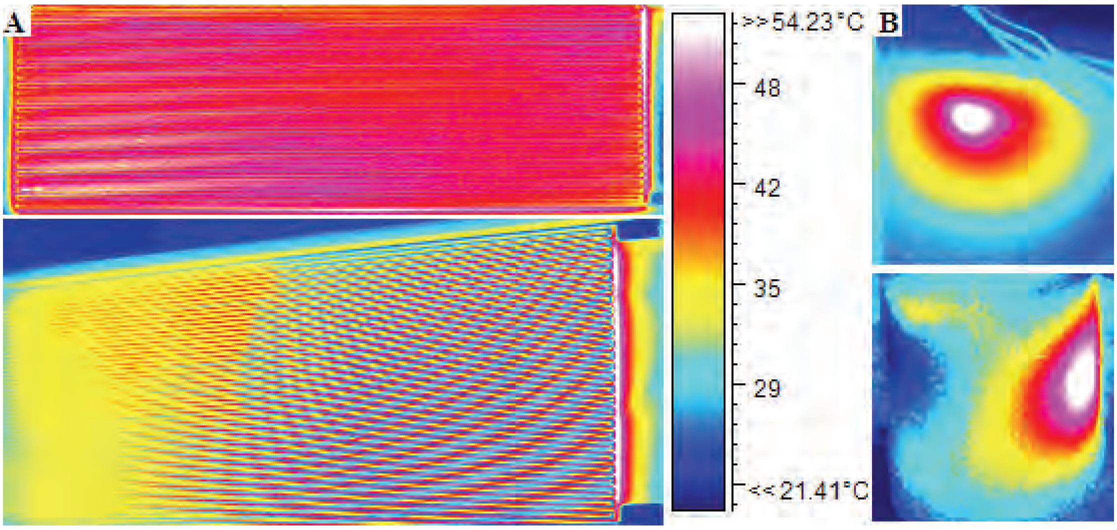

Figure 7. Photos with IR camera of: A - the temperature distribution on the surface of the PCB heating elements;
B - cylindrical container with Glauber's salt, heated with cartridge heater.

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