THERMODYNAMIC BEHAVIOUR OF A HEATING SYSTEM BASED ON TWO PHASE-CHANGE MATERIALS

G. BAJNÓCZY and A. ZÖLD*
Department of Physical Chemistry
* Laboratory of Builiding Physics
Technical University, H-1521 Budapest

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Abstract

The combined application of phase-change materials having low and high phase change temperature makes possible to increase the heating performance of the built-in latent energy-storage heatings and at the same time to conserve their self-stability. Materials suitable for this purpose are: calcium chloride-hexahydrate and stearic acid. These materials are placed in elements made from tubes. Segregation was inhibited by the special design of electric heating plates situated in the elements.

With an alternating disposition of various elements the fin effect can be well exploited. In the article data are presented to illustrate operational strategy and performance of the systems.

Introduction

Various possibilities are known for the utilization of latent energy-storage materials in heating technique and for temperature stabilization [1], [2], [3], [4].

One of the ways of the realization of latent energy-storage heating systems is to build the storage tank containing the phase-change materials (PCM) into the wall or floor structure of buildings. In this way they operate like a radiant heating system which is advantageous from energetic considerations and from the point of view of thermal comfort.

A problem related to the performance and performance control of these heating systems is the insufficiency of the heating performance for a specific PCM; this insufficiency may be caused by an excessively high heating load and/or a very low surface temperature of the incorporating structure owing to the layered structure (e.g. carpet covering).

This problem apparently can be solved by use of a PCM of higher phase-change temperature. However, it seems to be impracticable from several points of view. Systems with higher phase-change temperature show a reduced self-stability. Self-stability means that the heating performance (q) is the function of the temperature difference existing between heating surface and room temperature ($q=\alpha(t_s-t_r)$), where $\alpha=f(t_s-t_r)$. In case of a low heating surface temperature (t_s) even an insignificant change in the room temperature may cause an important change in the heating performance, hence the system will be self-regulated without automatics. This effect is relatively less prevailing in case of higher heating surface temperatures. For this reason under given weather conditions, when the system should be operated with reduced performance, it will be difficult to maintain exactly the prescribed indoor temperature; furthermore in such cases only one part of the heating elements should be switched on, consequently an uneven distribution of the surface temperature is expected. On the other hand, *PCM*s of higher phase-change temperature are usually more expensive than those of lower phase-change temperature.

In consequence of the above-mentioned reasons it is more advantageous to assure the required heating performance in such a way that *PCM*s of two sorts—one having a lower and the other a higher phase-change temperature—are built into wall and floor structures. Under mild weather conditions it is sufficient to switch on only the heating elements having low phase-change temperature; their self-stability is also favourable. With decreasing outdoor temperature and increasing performance requirements, as the next step, the heating elements having higher phase change temperature can be switched on, finally under low outdoor temperatures both element types can be set into action.

Phase change materials

In the selection of phase-change metarials destined to be built into buildings and building structures one must be sure that the material has a lifetime nearly equal to that of the whole system.

The two different phase-change materials utilized, i.e. stearic acid (m.p.: 55—60°C) (*H*) and calcium chloride hexahydrate (m.p.: 28°C) (*L*) were placed in a polyvinyl chloride tube. For stearic acid a polyvinyl chloride tube can be used only in cases where the system is embedded in concrete, if not, the tube material should be polypropylene. The melting of the material is assured by an electric heating plate situated in the tube. The heating plate contains a resistance wire embedded in synthetic resin.

For the lifetime of the tubes filled with stearic acid no limiting factors are known, since stearic acid has a congruent melting character and an inclination to form homogeneous nodules.

However, in the case of calcium chloride hexahydrate the phenomenon of supercooling and the segregation of α-$CaCl_2.4H_2O$, which has an irreversible damaging effect, should be taken into account. The supercooling of the heat storage material can be prevented by using 0.5–1% of a 1:1 mixture of strontium chloride hexahydrate and strontium hydroxide octahydrate. It is recommended to use the material in pressed tablet form [5].

The elimination of segregation of α-calcium chloride tetrahydrate was assured by modifying the composition of the heat storage material and by the appropriate placing of the heating plate. By using a heat storage material of lower $CaCl_2$ content ($CaCl_2 : H_2O = 1 : 6.3$ mol ratio) than that of the peritectic transformation point of the calcium chloride hexahydrate the formation of calcium chloride hexahydrate as crystallizing phase during the cooling of the heat storage material can always be assured.

The electric heating plate placed vertically in the centre line of the tube assures by thermoconvection which takes place during the melting cycle, the dissolution of the eventually formed α-calcium chloride tetrahydrate, furthermore it assures a more diluted composition after stopping the energy supply than the pritectic composition [6].

Factors influencing the heating performance

In relation to the disposition of heating elements (called in henceforth elements of low and high melting temperature, respectively and marked by L and H), the fact should be taken into account that the heat loss of the system (the heating performance) depends among others on the strip width of the incorporating structure (henceforth floor structure), belonging to each heating

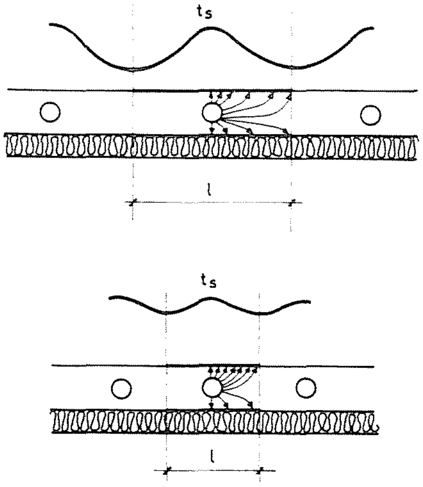

Fig. 1. The fin effect

element. For this floor strip operates like a fin: the greater the distance between heating element axes, the greater is the heat flow from the heating element to the room. Naturally there exists a nonlinear relationship: the efficiency of wider strips will be depreciated by decreases in temperature (Fig. 1). The fin effect explains also the fact that the heat loss of a specific floor surface increases disproportionately with the density of the heating elements; although the average surface temperature rises, the width of a fin belonging to one heating element (and consequently its heating surface) decreases. This effect is well represented by the diagrams in Figs 2 and 3. Figure 2 shows the heat loss of a

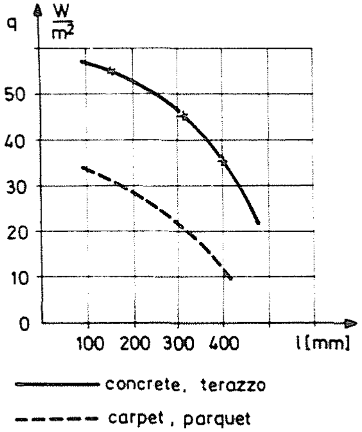

Fig. 2. The specific heat flow from the floor surface insulated differently as function of the distance between heating tubes (i.d. 90 mm). PCM: $CaCl_2.6.3H_2O$. Air temperature: 20 °C

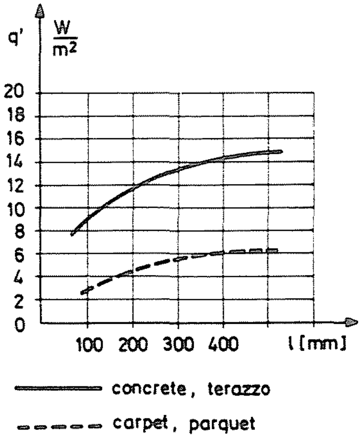

Fig. 3. The heat loss of a specific heating element length as function of the distance between heating tubes (i.d. 90 mm) PCM: $CaCl_2.6,3H_2O$. Air temperature: 20 °C

specific floor surface as function of the distance between elements, in case of a good insulating floor covering (e.g. carpet covering) and in case of a bad-insulating one (e.g. cast stone). The heat loss of a specific heating element length is illustrated as function of the same factors in Fig. 3. The diagrams were constructed on the basis of results calculated using the flow in network method, some points of the curve were controlled by measurements.

Disposition of the heating elements

Conforming to the preceding considerations, it would be a faulty step to elaborate the two-media built-in *PCM* system in such a manner that *L* heating elements are concentrated on one part of the surface and the *H* heating elements on the other part, because the fin effect would be in this case less exploited, moreover, if only one group of elements is switched on, the temperature distribution is also uneven.

A suitable way of building-in is the alternating disposition of elements *L* and *H*. In this case, when only the *L* elements are switched on, the wide fin existing between two-two adjacent *L* elements increases the specific heating performance to such an extent that it surpasses the performance achieved by a non-alternating building-in method. The temperature distribution in the floor structure is not substantially influenced by the presence of *H* elements and naturally in this case no phase change occurs in the *H* elements.

If higher performances are needed both *L* and *H* elements are switched on. Though the specific performance data related to one element will be reduced in this case (because of the reduced width of the fins), these reduced specific performances give together a greater total performance.

Performance calculations

The process can be followed by calculation. For this purpose—neglecting the heating element layers—heat transport is supposed to be a two-dimensional process, that is to say a section of the structure will be examined. The structure can be decomposed into grid elements. Grid elements at the structure surface adjoin grid elements representing the air and envelopping structures of the room, while these latter adjoin grid elements representing the environment. Each grid element can be characterized by the following data:

— temperature;

— source power (value given for the grid element representing the electric heating plate during the switching on time, for the environment it is infinite, the other nodes are neutral).

— capacity (in general a given value, in case of *PCM* it is an independent value for the solid and for the liquid phase, with an eventual branching depending on the actual node temperature).

The relationship between individual nodes is characterized by the overall conductance. This conductance depends in the case of structural nodes on the geometrical dimensions and conductivity, and in case of elementary surfaces contacting air also on the film coefficient. Using these data the heat flows between nodes can be calculated. In case of nodes representing the *PCM* a different conductivity will be considered with the conditional branching which depends on the actual node temperature. If the temperature passes from below a $t_{pc} = \delta t$ limit, the difference between heat flows influent into the nodes and currents outflowing will be used for the isothermic phase change. The energy necessary for a complete phase change can be assigned to each node and the temperature rises only after this energy has been supplied. The process can be similarly described using an assignation to a $t_{pc} + \delta t$ limit in the time of phase change energy release. In the intermediate times the solid phase and the liquid phase are supposed to be homogeneously distributed in space.

The performance needs eventually justify the use of *L* and *H* elements in unequal numbers. This is naturally permitted, but in this case in the section betweèn adjoing elements of the same type the fin width remains unchanged.

Some calculation results are summarized in Table 1.

Table 1

Specific heat loss in case of various dispositions
Tube diameter: 90 mm, Tube distance: 160 mm;
$t_r = 20$ °C

Disposition of the tubes	Heating W/m² cast stone	performance W/m² carpet
	floor covering	
L-L-H-L-L-H	84	47
L-H-L-H	96	55
H-H-L-H-H-L	105	62

The data relate to *L*: calcium chloride-hexahydrate; *H*: stearic acid bases *PCM*s and to daily 8 h charging and 16 h discharging time. Similar systems can be designed naturally not only as floor heating but also as wall or ceiling heating systems.

The calculation results were controlled for some versions also in experimental sections of 3 m², very well insulated along the side plates. The deviation of the measured and calculated results was within 10%. The reason for the deviation was in addition to measurement errors presumably the fact that in reality the advection in a liquid phase *PCM* is not as perfect as it was supposed in the calculation.

The utilization of two-media systems enlarges the sphere of application possibilities of built-in *PCM* heating systems.

References

1. Boer, K. W., Higgins, J. H., and O'Connor, J. K.: Proc. Intersoc. Energy Convers Eng. conf. 10th. pp. 7–13 (1975)
2. Lane, G. A.: The Int. J. of Ambient Energy, *1* (3) pp. 155–168 (1980)
3. Abhat, A., Aboul-Enein, S., and Malatidis, N. A.: Int. TNO-Symp. "Thermal Energy Storage" Nov. 5–6. pp. 266–280 (1980)
4. Page, J. K. R. and Swayne, R. E. H.: Int. Conf. on Energy Storage, Brighton, UK. April 29–May 1. pp. 165–170 (1981)
5. Bajnóczy, G. and Zöld, A.: Heizung, Lüftung, Klimatechnik, Haustechnik. *14* (7) pp. 289–293 (1983)
6. Bajnóczy, G. and Zöld, A.: Applied Energy *10* pp. 97–105 (1982)

Dr. Gábor Bajnóczy
Dr. András Zöld
H-1521 Budapest