Pergamon

Cement and Concrete Research, Vol. 28, No. 8, pp. 1165–1177, 1998

0008-8846/98 $19.00 + .00

PII S0008-8846(98)00081-7

HYDRIC PROCESSES ASSOCIATED WITH SALINE SOLUTIONS, STUDIED BY MEANS OF SELECTIVE INFRARED THERMOGRAPHY

E. Gayo-Moncó[1]* and J. de Frutos†
*Instituto Eduardo Torroja de Ciencias de la Construcción (CSIC), P.O. Box 19002,
28033 Madrid, Spain
†Escuela Técnica Superior de Ingenieros de Telecomunicaciones (UPM),
Ciudad Universitaria s/n, 28040 Madrid, Spain

(Received September 24, 1996; in final form May 14, 1998)

ABSTRACT

The presence of salts diluted in water modifies the hydric behavior of building materials. Using selective infrared thermography, a study has been developed on hydric processes related with materials. Capillary action as well as evaporation are studied, and also the dependence of each one according to the type of saline solution used. In the particular case of the evaporation process, the study has been completed with an analysis of the loss of weight of the material. Through this study, the hydric behavior of different saline solutions can be determined and the potentiality of the selective infrared thermography reveals itself as a very useful non-destructive analysis technique. © *1998 Elsevier Science Ltd*

Introduction

Infrared thermography has been proven to be a useful technique for studying some different processes of building deterioration (1). The characteristics of the technique, already presented in previous papers (2,3), make it possible to locate almost immediately the failures related to the absence of insulation, thermal bridges and other processes only involving changes of temperature in materials (4,5).

A second interesting study theme, also related with building deterioration, would cover the analysis of damp areas. In this case, a double goal needs to be accomplished: first, determining if deterioration is due to the presence of water; and second, locating the source of the water so as to be able to fix the source of the damage.

Infrared thermography has proved to be a valuable technique for this kind of analysis in propitious cases, as when the material absorbs pure water and when external conditions are adequate for the measurement (low particle content in atmosphere and short distances between object and camera) (6,7).

However, in actual cases of decay, two kinds of problems arise that complicate the study. One is that in actual deterioration, materials never hold pure water (the existence of salts).

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[1] To whom correspondence should be addresssed.

Their presence can modify significantly the hydric behavior due to alterations in the structure of the material: chemical reactions, precipitation (thus, decreasing the porosity of the material), partial dissolution of the material (thus, increasing its porosity), etc. (8,9).

A second problem is that external conditions, in general, are not the most adequate for the facilitation of thermographic measurements. In most of the monuments studied by the authors, there were high contents of CO_2 and high relative humidity that diminished the signal coming from the objects until, in some cases, it was impossible to get any data. In order to solve this second problem, the so-called Selective Infrared Thermography has been developed. This technique is based on the use of interferencial filters that select different detection bands. The worthiness of this technique has been proved in former studies (10).

The study of the different hydric processes in building materials with saline solutions was developed basically by trying to compare laboratory tests and actual monuments. The presence of salts deepens the damages in the material. The places where salt precipitation occurs, for instance, are of chief importance in building restoration. Salt alters the hydric balance inside/outside, and favors condensation processes; precipitation of salts on the surface of the material does not affect it very much, but when this precipitation occurs in the interior, cracks related with crystallization phenomena can appear. In addition, the high hygroscopic capacity of salts can cause an increase of the water content of the material, making it more vulnerable to deterioration. Usually, the areas where salts precipitate are related to the salts' content of equilibrium moisture. The condition of supersaturation and precipitation happens when the equilibrium moisture of salts is higher or equal to relative humidity of the environment. In this particular case, the salts used have very high values of equilibrium moisture (75.5% in the case of NaCl, and 91.4% for Na_3PO_4, both at 20°C) and they are very frequent in the monuments studied. Therefore, it is a matter of logic to believe that any decrease of the relative humidity will favor chloride precipitation inside the material. This work focuses the study of the influence of saline solutions in hydric processes.

Experimental Phase and Results

The characteristics of the filters used, already mentioned in former works (10), can be summarized as follows. The filters used are centered, respectively, in 2.7 μm (H_2O filter) and in 4.3 μm (CO_2 filter). They have a 0.5-μm band width. The optical thickness of each layer is $\lambda/4$ to the respective wave length, and the transmission coefficient is 40% and 60%, respectively.

Capillary Tests

Tests were carried out on plaster samples of equal size and shape, and of well-known characteristics. Before starting the test they were kept for 48 h in an oven at 40°C. After cooling, they were positioned vertically in a black box to avoid environmental radiation, with their bases soaking in the solution to be studied, at 20°C. The bottom surface of the samples was kept in contact with the solution for 40 min. During this period radiation measurements were taken with each of the interferencial filters.

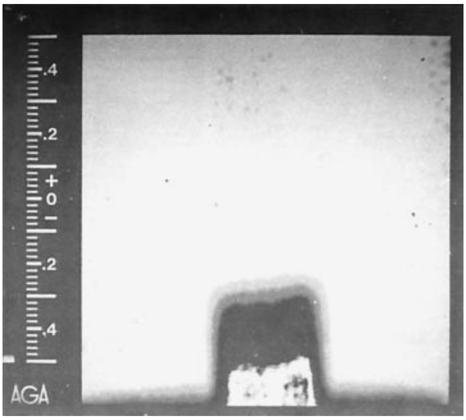

FIG. 1.
Thermogram corresponding to test with NaCl solution and no filter. Capillary test.

Evaporation Tests

As before, samples were kept in an oven at 40°C for 48 h. After cooling, they were immersed for 2 h in the solution to be studied. Then they were put in vertical position in a black box in order to avoid uncontrolled radiations, and they were not in contact with water. The radiation was measured using each one of the interferencial filters. Measurements were taken again after 48 h. Weight measurements were also taken on the materials studied. The results are shown in the following figures.

Discussion of the Results

The purpose of evaporation and capillary suction tests is to get an estimation, by means of infrared thermography, of the hydric behavior of materials when they are submitted to

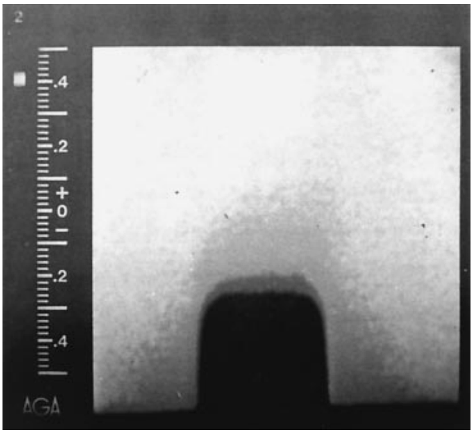

FIG. 2.
Thermogram corresponding to test with Na_3PO_4 solution and no filter. Capillary test.

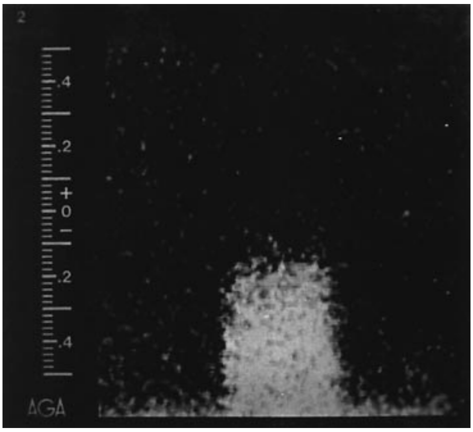

FIG. 3.
Thermogram corresponding to test with H_2O filter and NaCl solution. Capillary test.

different salt solutions. These tests were carried out on samples made of gypsum, because this material is very absorbent. It is easy to detect he movement of water even in very narrow bands; recall that interferencial filters limit the detection bands of the thermocamera to bands of about 0.5 μm width (10).

Capillary Tests

From the study of the thermograms corresponding to tests with no filter, a bigger wet area and more homogeneity of the damp zone is observed in the case of test with NaCl solution with respect to those with Na_3PO_4 solution (Figs. 1 and 2). In the first case (Fig. 1), wet and dry zones can be detected in the same thermal level value. This implies a higher inhomogeneity in the distribution of the humidity. Moreover, in all the cases, the external isotherm is wider in the lower part of the sample, and the internal is flat. That means that water rises more

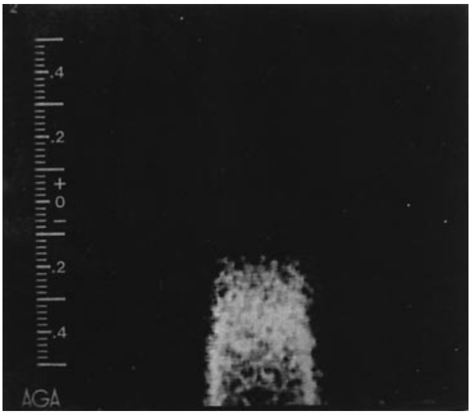

FIG. 4.
Thermogram corresponding to test with H_2O filter and Na_3PO_4 solution. Capillary test.

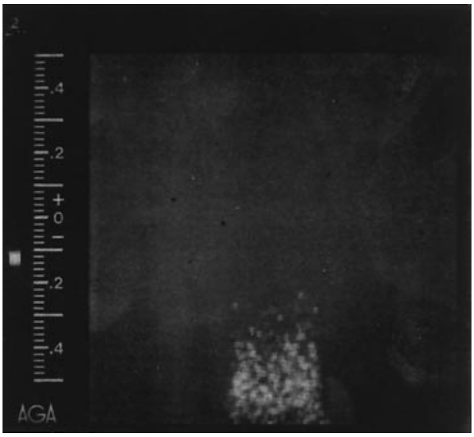

FIG. 5.
Thermogram corresponding to test with CO_2 filter and NaCl solution. Capillary test.

quickly through the internal layers of the material, remaining in the lower part of the prism in the external surfaces, where the most important processes of evaporation occur.

This characteristic of the isotherms appears when using a water filter (Figs. 3 and 4). The wedge-shaped isotherms, in the case of saline solutions, indicate a higher level of water in the lower part of the prism that moves up along the internal pores. This phenomenon can be observed more accurately in the case of the Na_3PO_4 solution (Fig. 4), in which two isotherm levels can be differentiated using the water filter. This means that the water is mainly trapped in the lower part of the sample.

This information is ascertained by analyzing this process by means of interferencial filters (Figs. 3 to 6). This analysis provides us with data that help in interpreting associated phenomena. Meanwhile, the CO_2 filter reveals a variation in temperature in the sample because of the presence of water.

For both solutions, the water filter helps determine how the water moves inside the

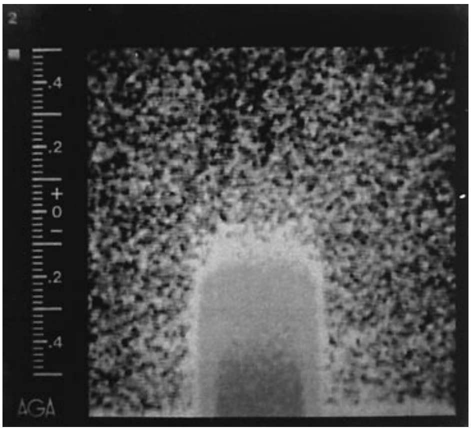

FIG. 6.
Thermogram corresponding to test with CO_2 filter and Na_3PO_4 solution. Capillary test.

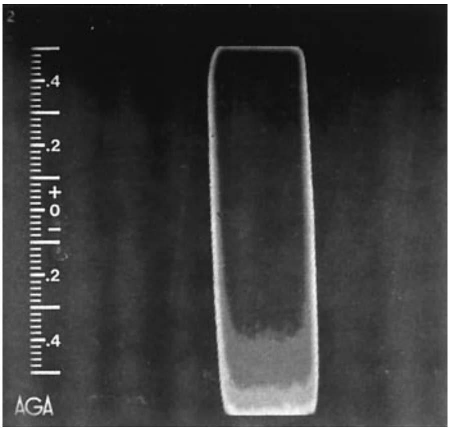

FIG. 7.
Thermogram corresponding to test with NaCl solution and no filter during the first evaporation day.

material and, most importantly, the possible initiation of the evaporation process in the samples. To sum up, it appears that NaCl solution (Fig. 3) reaches slightly higher peaks than those observed without filter, that the water content within the material is quite uniform, and that the evaporation process starts out mainly at the bottom of the sample.

On the other hand, in Na_3PO_4 solution (Fig. 4), a gradient in the distribution of the solution inside the material can be noticed. Moreover, it can be seen that the solution reaches a higher peak than that registered without filter, and that there is no evaporation on the sample.

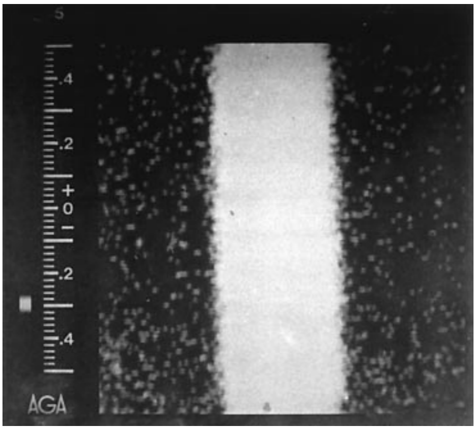

FIG. 8.
Thermogram corresponding to test with water filter and NaCl solution the first evaporation day.

TABLE 1
Width of the external isotherms in the thermograms obtained with water filter.

	Isotherm width (cm)	
	First day	Third day
Distilled Water	2.1	1.6
NaCl Solution	1.9	1.8
Na_3PO_4 Solution	1.6	2.0

Evaporation Tests

The results obtained by analyzing evaporation processes by means of selective infrared thermography are shown in Figures 7 and 18. In addition, samples were periodically weighed until the reached a constant weight. The curves of weight loss are shown in Figure 19.

In the thermograms corresponding to tests without filter (Figs. 7, 10, 13, and 16), the whole sample studied can be observed and the evolution of the water in the first 48 h of evaporation can be followed. During the first day (Figs. 7 and 10) the same evolution of the water happens independently of the type of the solution: isotherms are more neatly seen in the lower part of the samples in all cases studied. This fact proves again that water is accumulating in the lower part of the sample due to the weight of the water column.

If thermograms corresponding to the measurements taken at the third day of the no-filter early evaporation process (Figs. 13 and 16) are compared to those obtained at the first day (Figs. 7 and 10), important changes can be observed (compare Figs. 7 and 13 corresponding to the NaCl solution and Figs. 10 and 16 corresponding to the Na_3PO_4 solution). In these cases the water stays in the central part of the material, and this is why the darkest isotherms appear in this zone.

Salts, thus, are trapped in the internal part of the material and, due to their hygroscopic

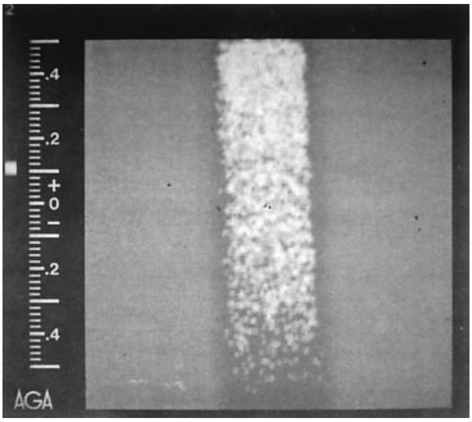

FIG. 9.
Thermogram corresponding to test with CO_2 filter and NaCl solution during the first evaporation day.

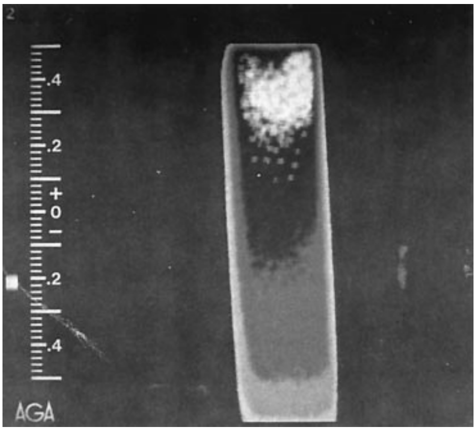

FIG. 10.
Thermogram corresponding to the test with Na_3PO_4 solution and no filter during the first evaporation day.

nature, absorb water from their surroundings. This phenomenon favors water accumulation in this area of the material, as detected by selective infrared thermography.

Regarding thermograms corresponding to the test carried out using water filter (Figs. 8, 11, 14, and 17), it can be seen that:

- The evaporation process begins earlier in the sample that has been immersed in the NaCl solution and later for that in Na_3PO_4. The water steamed off the material remains in its nearest environment, and thus the surrounding isotherm indicates the water losses. In the thermogram corresponding to the test carried out with NaCl (Fig. 8), a very dense isotherm appears covering this area, while in the thermogram corresponding to the test carried out with Na_3PO_4 (Fig. 11) there is no isotherm covering it. That means that the material evaporating NaCl solution had a bigger loss of water during this period than the

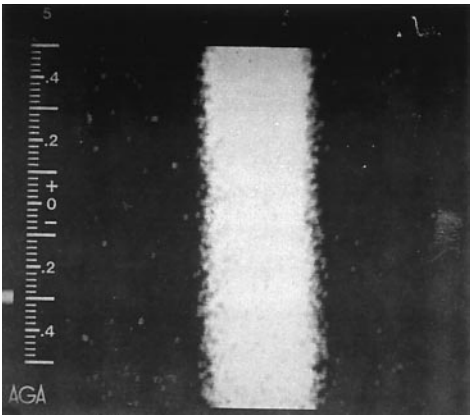

FIG. 11.
Thermogram corresponding to test with H_2O filter and Na_3PO_4 solution during the first evaporation day.

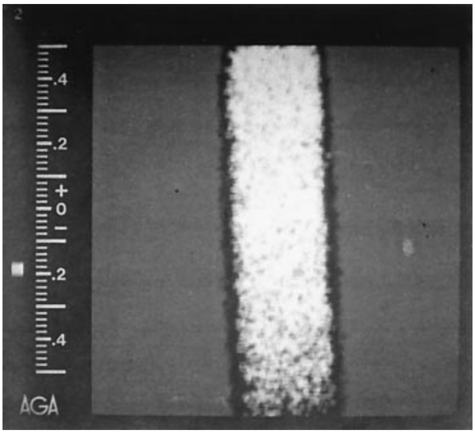

FIG. 12.
Thermogram corresponding to test with CO_2 filter and Na_3PO_4 solution during the first evaporation day.

one subject to evaporation with Na_3PO_4. This latter had a small loss in the same period of time.

- During the third evaporation day (Figs. 14 and 17), the material subject to an evaporation process, with Na_3PO_4 solution, is losing the biggest amount of water (Fig. 17), opposite to the material with NaCl (Fig. 14).

Given that infrared thermography measures the radiation coming from the surface of the body studied, and the water filter enables the detection of the evaporated water next to the surface, the width of the isotherm of the external material (measured with an H_2O filter) is to be related to the amount of evaporating water. The width of the external isotherms (in cm), shown in Table 1, agrees with the results already stated.

Finally, CO_2 filter provides with a more blurry image of the whole sample (Figs. 9, 12, 15,

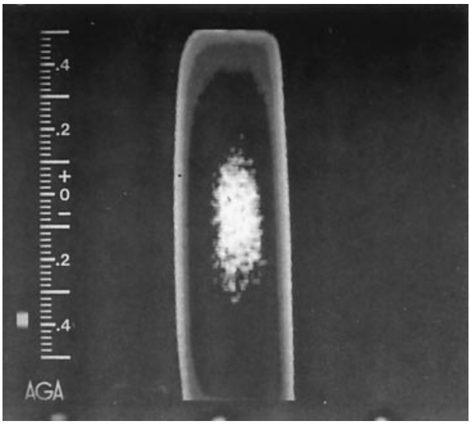

FIG. 13.
Thermogram corresponding to test with NaCl solution and no filter during the third day.

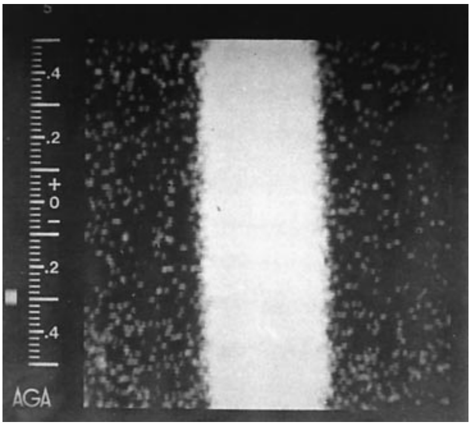

FIG. 14.
Thermogram corresponding to test with H_2O filter and NaCl solution during the third evaporation day.

and 18). It has already been explained (10): that in this work band (4 to 4.5 mm) effects of water emission have not been practically detected, this is why the light obtained from the material is weaker.

In thermograms corresponding to CO_2 filter it can be seen how homogeneously spread is the water in the material; for that reason, the same isotherm covers its whole surface (Figs. 9 and 12). However, during the third day, the evaporation processes has changed as the thermograms indicate (Figs. 16 and 18). In this figure, the same isotherm covers the external part of the material corresponding to the dry zone.

Finally, Figure 19 indicates water loss for each of the samples during the evaporation process. This evolution agrees with the aforesaid.

During the first day the slope of the curve corresponding to the test with distilled water is

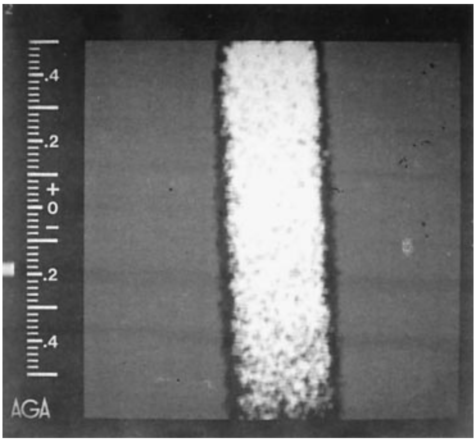

FIG. 15.
Thermogram corresponding to test with CO_2 filter and NaCl solution during the third evaporation day.

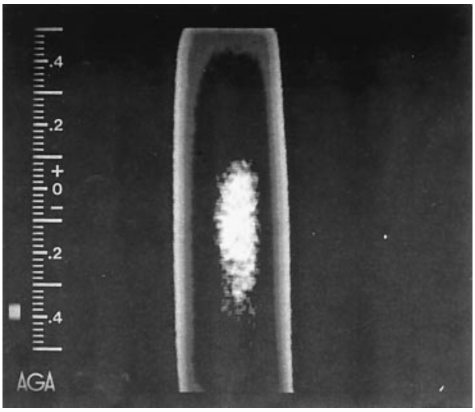

FIG. 16.
Thermogram corresponding to test with Na_3PO_4 solution without filter during the third evaporation day.

the steepest and the curve corresponding to the Na_3PO_4 is the lower; this means that during this period of time, the stronger evaporation corresponds to the test with distilled water and the weaker with that using Na_3PO_4 solution.

In the same way, from the study of the curve part corresponding to the third evaporation day, it can be noticed that the curve corresponding to the test with distilled water is practically horizontal, that means that there is little evaporation and the isotherm covering the external part of the sample is very narrow. The steepest slope corresponds to the test carried out with Na_3PO_4 solution, and therefore this is the material which evaporates a bigger amount of water and the surrounding isotherm is the denser.

Conclusions drawn from the selective infrared thermography analysis only refer to the evaporation speed of the different saline solutions and to the distribution of water in the

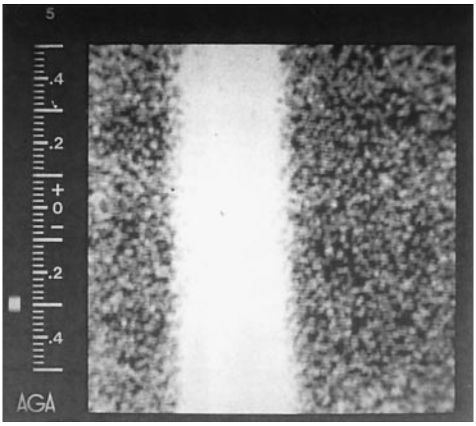

FIG. 17.
Thermogram corresponding to test with H_2O filter and Na_3PO_4 solution during the third evaporation day.

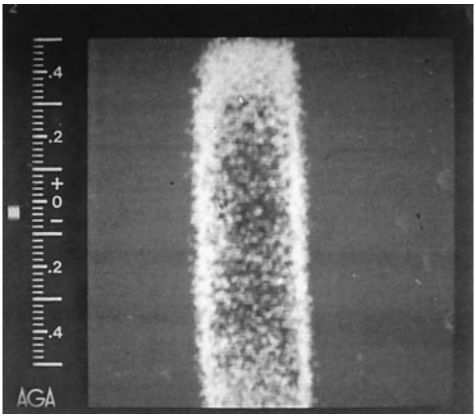

FIG. 18.
Thermogram corresponding to test with CO_2 filter and Na_3PO_4 solution during the third evaporation day.

material; and they are in agreement with the results based on the curves of weight loss of these materials.

In parallel to the thermography measurements, the material was weighed in order to determine the weight loss from water. When weights (in percentages) reached in the equilibrium (Fig. 19) are analyzed, noticeable divergences among the different solutions can be noticed; recall that, as the material is always the same, all variations on curves result from the saline solution. The sample immersed in distilled water reaches first the equilibrium and loses practically all the water previously absorbed. In experiments made with saline solu-

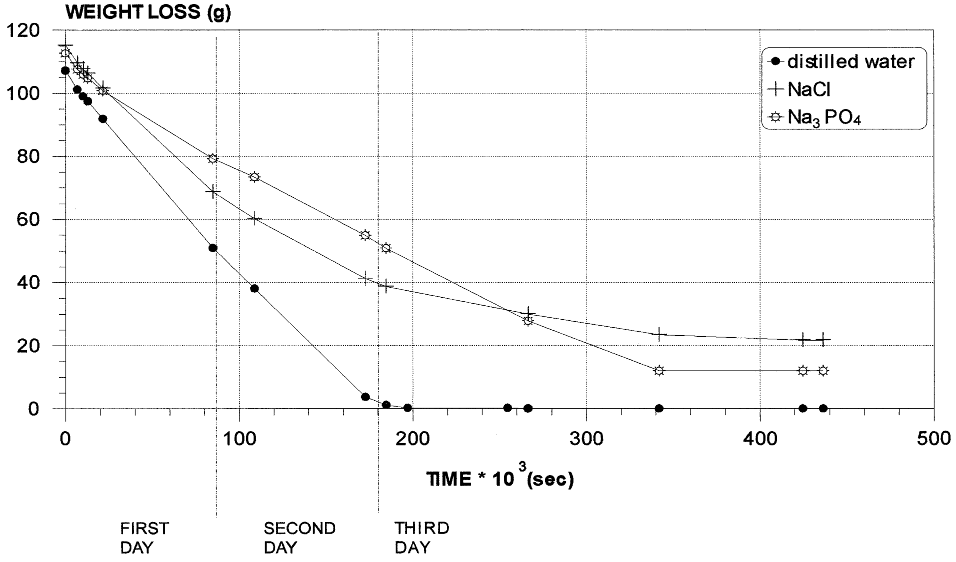

FIG. 19.
Weight loss curves in evaporation processes.

tions, the balance is reached, for weight increasing values, at around 20% with respect to the dry mould. This means that, either the solution itself is preventing the total evaporation of the water held in the body, or the deposits of salt augment the weight of the sample.

Conclusions

Based upon these studies, classic infrared thermography appears to be a powerful tool for non-destructive analyses, but is limited by different external factors that sometimes make its use unwanted.

With the purpose of overcoming limitations in applying the measurement technique based on classic infrared thermography and enhancing the usage capacity, additional techniques have been developed resulting in selective infrared thermography (selection of bands by means of specific interferencial filters).

When detecting the presence of saline solutions in the material, selective infrared thermography is very useful, since it enables determination of the different types of salts by studying each salt behavior.

Results obtained by means of selective infrared thermography reveal that an adequate selection of detection bands (in this case by means of interferencial filters), allows visualizing and analyzing the different processes of water movement in materials, and the joint analysis of the information given by each one of the filters reveals the process implied in a specific material.

Acknowledgment

This research has been conducted under the sponsorship of the Spanish Dirección General de Investigación Científica y Técnica.

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