EXPERIMENTAL ANALYSIS OF FLUID AND VAPOUR TRANSPORT PROCESSES DEPENDING ON THE MOISTURE CONTENT AND CONCENTRATION OF DETERIORATING SALTS AGAINST THE BACKGROUND OF DIFFERENT MASONRY MATERIALS

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ABSTRACT

Desalination by applying poultices is one of the most gentle and effective treatments. Hence it is a most favourable means for revitalisation of salt contaminated buildings. This method is based on balancing concentration gradients in the pore system filled with salt containing moisture. Initially specific gradients e.g. moisture or ion concentration are set between the pore solution of the salt contaminated specimen and the poultice to reduce the salt concentration in the specimen. However, all of these salt transport processes are only possible with at least a minimum of liquid moisture. Therefore it is necessary to know the amount of liquid and vapour moisture involved in the drying processes. Besides the quantification of liquid and vapour water it is necessary to define the influence of climatic conditions, kind and concentration of the salt solution and the liquid or vapour moisture transport.

KEYWORDS: Moisture transport, salt transport, materials

INTRODUCTION

The damage occurring in valuable buildings through salt deterioration is a very complex process. The water has a major influence. It serves as a transport medium and has a decisive influence on the processes of solution and crystallisation [1].

For the analysis of preventive and revitalising measures it is necessary to separate the different mechanisms having an impact on the transport processes. Basic transport processes of deteriorating salts, which are possible to occur, are the advective and convective moisture transport and ion diffusion. The dominance of one main transport process is caused by specific climatic and boundary conditions. Therefore setting the right climatic and boundary conditions makes it possible to separate one particular transport process for detailed analysis.

Investigations have been carried out into the influence of the moisture dependent transport of salt ions and salt solution in porous building materials under varying climatic and boundary conditions. As one result the influence of different masonry materials and salt solutions on the liquid and vapour moisture transport should be clarified.

For research on the salt transport processes either for revitalisation or contamination it is necessary to distinguish between the vapour and liquid moisture transport because the salt can only be transported within the liquid phase.

One desalination technology, which is based on the existence of moisture in the pore system, is the application of bentonite-cellulose-sand poultices [2]. This method was found to be a very gentle and effective treatment and therefore chosen for these investigations. Because of the complex background of the vapour and liquid moisture transport in the case of desalination processes, a general investigation into drying experiments of building materials without the application of poultices had been carried out. These experimental investigations were focused on the influence of the climatic conditions as well as on the kind and concentration of the pore solutions.

EXPERIMENTAL INVESTIGATION AND RESULTS

To investigate the required duration for the application of the poultice that leads to a measurable amount of desalination, salt transport experiments were carried out. For the effectiveness of desalination the duration of available liquid moisture is essential. Therefore it is necessary to determine the amounts of liquid and vapour moisture transport during the drying of the materials. This topic of drying processes of building materials was the subject of the second investigation.

DESALINATION BY POULTICE APPLICATION

The experimental conditions were chosen close to the practical situation. The cylindrical specimens (diameter: 5 cm) were made from fine-grained sandstone with a length of 30 cm. They were homogeneously penetrated with 0.5 molar (M) Na_2SO_4-solution. For the desalination a bentonite-cellulose-sand poultice (thickness: ~2 cm) was applied (Fig. 1). All surfaces except the side of the poultice were covered. This resulted in a one-dimensional transport.

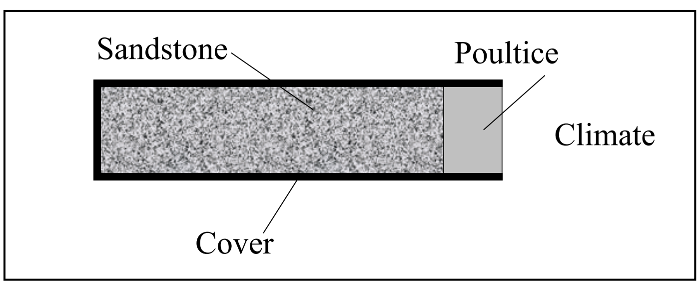

Figure 1 - Experimental Set Up

The experiments were carried out at climatic conditions of 65 % relative humidity and 23 °C. For the analysis of the effectiveness of different application durations the poultice was applied and the content of salt and water was determined at the end of each period. The data points in Fig. 2 are average values of about 2 cm sections. The water content was measured by weighing. The salt content was determined by ICP (Inductively-Coupled-Plasma). Therefore the concentration of the pore solution could be calculated in the sandstone and the poultice (Fig. 2).

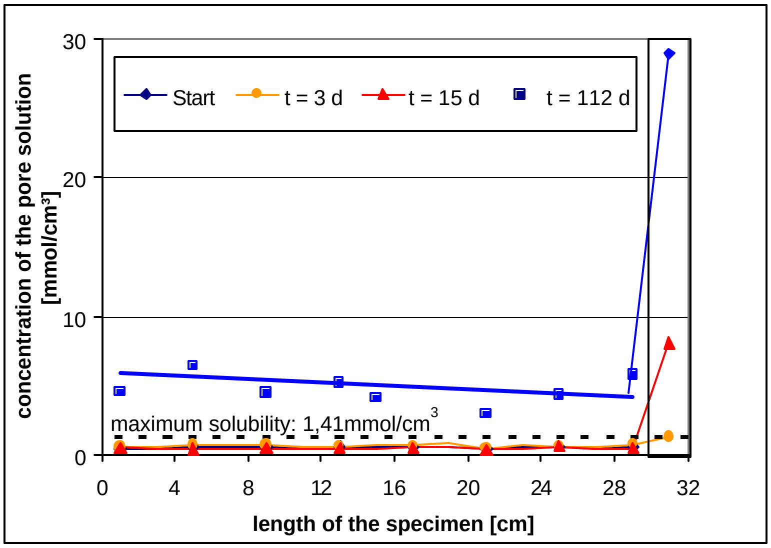

Figure 2 - Concentration of the Pore Solution in the Sandstone and the Poultice

Considering Fig. 2 it is obvious that up to 15 days of desalination the transport of the salt is done by advection, because the concentration of the pore solution of the sandstone does not change [3].

Between 15 and 112 days the concentration of the pore solution of the sandstone rises significantly. It even exceeds the limit of the solubility of the Na_2SO_4-solution 1.41 mol/l (23 °C). Therefore the crystallisation process starts in the pore system and makes a salt transport impossible. For a closer examination of the availability of liquid moisture in the pore system and therefore the possibility of salt transport, experiments were carried out to investigate the availability of the liquid moisture and also the influence of climatic conditions on this availability.

FURTHER INVESTIGATIONS INTO ION AND WATER TRANSPORT

The experimental investigations should also give a more quantitative explanation of the dominance of different transport processes taking place during the drying process. Therefore different parameters such as the climatic conditions (humidity and temperature), building materials, kind and concentration of the pore solution were varied.

These drying experiments were conducted with the same experimental setting as the desalination experiments. Cylindrical specimens were penetrated with either water or salt solution. They were covered on all sides except for one. This side was exposed to the climatic conditions. Therefore the transport processes could be considered as one-dimensional and isothermic. The loss of water, plotted against the square root of time is given schematically in Fig. 3.

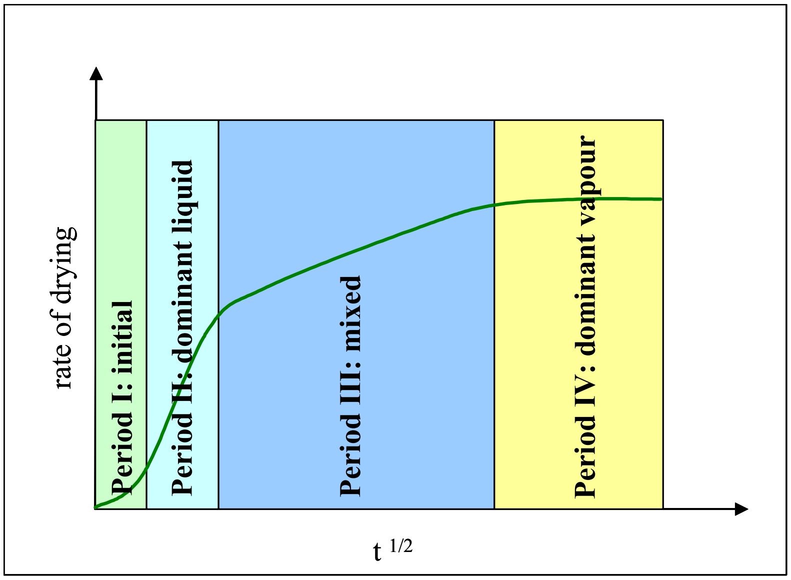

Figure 3 - Schematic Plot of the Square Root of Time Versus Rate Of Drying

The plot shows four different periods in the drying process. All periods can be characterised approximately by a linear form with different gradients denoting different speeds of drying. The different speeds of those periods are caused by the domination of one particular transport mechanism. Period I is characterised by reaching a constant evaporation at the open side and initiating the capillary transport. Period II is dominated by advective transport while Period III is characterised by an increase in vapour moisture transport. In period IV the moisture transport is dominated by the vapour phase. The change in speed between the second and the third period is caused by the change in the dominance of the moisture transport in the liquid and vapour phase. Similar explanation of drying periods has been given by Bednar and Krischer [4, 5].

To determine the different influences of the climatic and boundary conditions on the four drying periods the results of the experimental investigations under those different conditions are shown in the diagram of Fig. 4. For the investigations shown in Figure 4 and 5, a fine grained sandstone was chosen. The specimens were penetrated with water (W), Na_2SO_4- or K_2SO_4-solutions (S) of different concentrations. The salt solutions were 0.5 M and saturated (sat.). In Fig. 4 the specimen was penetrated with Na_2SO_4-solution.

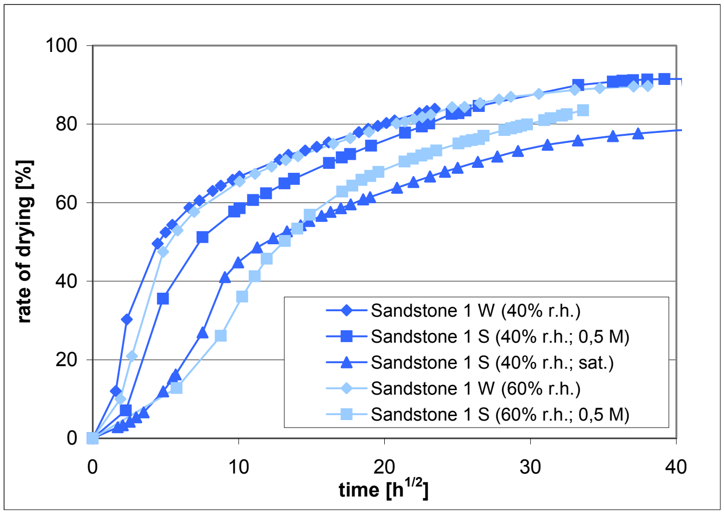

Figure 4 - Drying Process of Sandstone 1 at Different Relative Humidity, Kind and Concentration of the Pore Solution

Fig. 4 shows that the concentration of the pore solution has the strongest influence on the gradient of the second period whereas the function in the third period shows a parallel shift. Also the climatic conditions also have a distinct effect on the behaviour. At a relative humidity (r.h.) of 40 % the gradient of the second period is a lot steeper than at 60 % in the case of the saturation with the salt solution. This could be expected because the thermodynamic characteristics of salt solutions are much more sensitive to changes in relative humidity and temperature than those of pure water. The influence of the salt solution concentration is also shown by the different curves of the specimens penetrated with different concentrations of Na_2SO_4-solution.

Fig. 5 shows the drying curve of the specimen penetrated with K_2SO_4-solution. The relative humidity for this investigation was kept constant at 40 %. The temperature was varied between 25 °C and 40 °C. The concentration of the pore solution was also varied from 0.5 M to saturated.

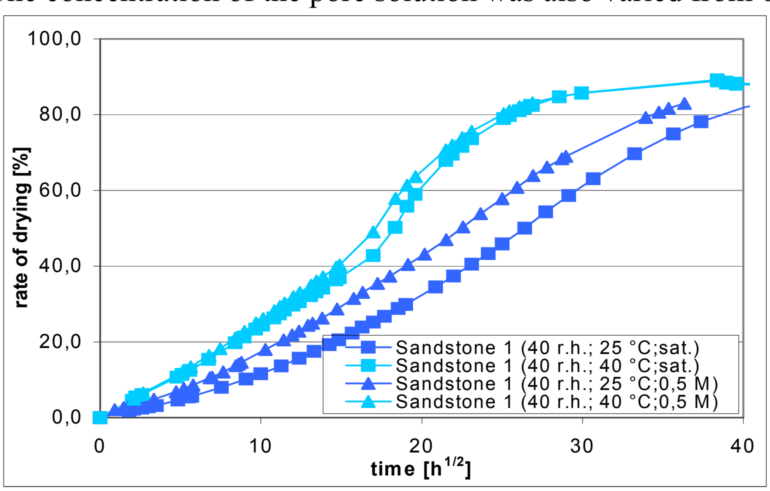

Figure 5 - Drying Process of Sandstone 1 at Different Temperature and Concentration of the Pore Solution

In the case of the K_2SO_4 penetrated specimens the four different drying periods are not as clearly separated as for the specimens with Na_2SO_4-solution. However there is also an obvious influence of the concentration of the pore solution. Figure 5 also shows that the specimen dries out faster at 40 °C than at 25 °C.

These simple drying experiments, where the results are plotted as rate of drying versus the square root of time, also make it possible to define the amount of vapour and liquid water transport. This can be determined by comparison of the drying for the specimens penetrated with water and salt solutions at different concentrations.

It is possible to calculate the concentration of the pore solution by determining the moisture and salt content of the specimens during the drying experiment at different time steps. An increase of the concentration of the pore solution defines the amount of vapour water transport. By determining the total loss in mass of the specimen it is possible to determine the amount of vapour and liquid transport in relation to the rate of drying (phase-defining-function). Therefore the whole water transport is the addition of liquid and vapour water transport.

Fig. 6 shows the phase-defining-function in the case of three different sandstones penetrated with 0.5 M Na_2SO_4-solution. The three sandstones differ in the binder and in the pore structure.

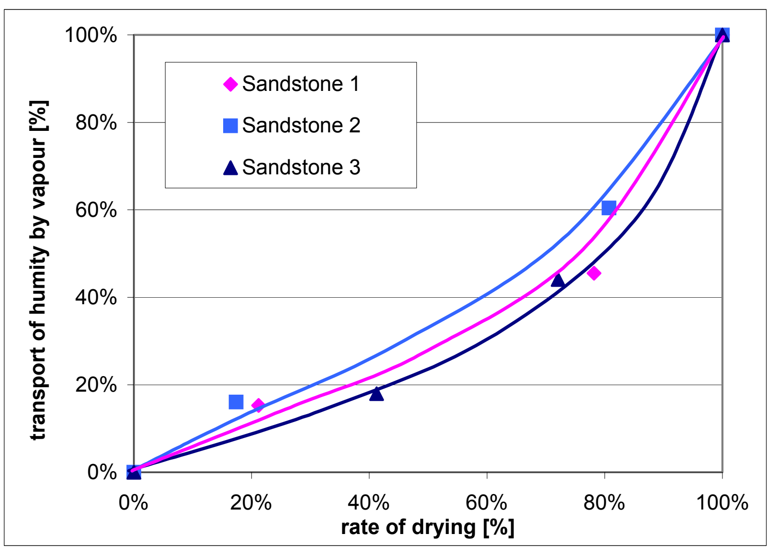

Figure 6 - Separation of Vapour and Liquid Transport During the Drying Process of Specimen Penetrated With 0.5 M Na_2SO_4-Solution

The phase-defining-functions of the specimens penetrated with saturated Na_2SO_4-solution are shown in Fig. 7. By analysing the plots of these measurements, where the phase of moisture transport is plotted against the drying rate (Fig. 6, 7), it seems that the curve of measured points has an exponential progression. This is also discussed by Grunewald [6] based on a thermodynamic derivation. Getting more data points would make the progression even more clear. Besides this, comparing the two plots, there is also a first indication that the function depends on the pore system.

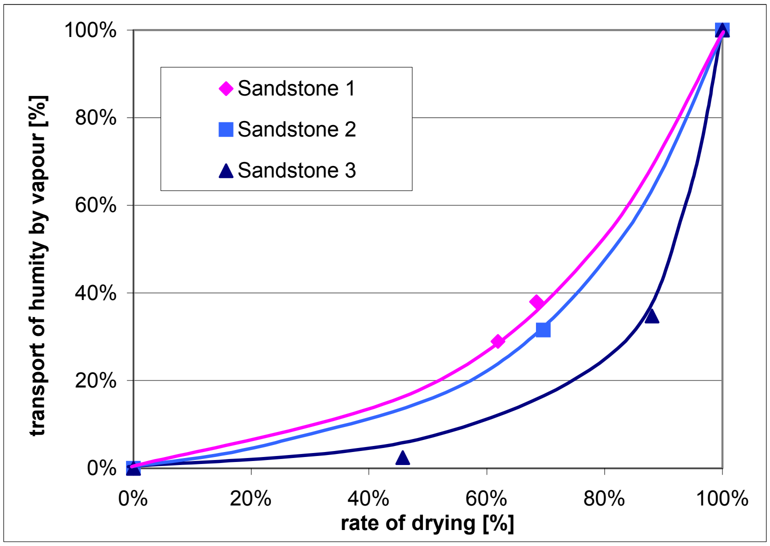

Figure 7 - Separation of Vapour and Liquid Transport During the Drying Process of Specimen Penetrated With Saturated Na_2SO_4-Solution

The fact that the amount of vapour moisture transport increases as the concentration of the salt solution decreases, confirms the interdependence of the concentration of pore solution and the phase of moisture transport.

SUMMARY

The experimental investigations of this work showed on the one hand the practical application of phase defining drying experiments and on the other hand the need for a theoretical understanding of several influences such as climatic condition, pore system, and kind and concentration of the pore solution on different moisture transport processes. From drying experiments it was shown that liquid and vapour water transport can be distinguished. These experimental investigations made it possible to determine a phase-defining function for multi-phase systems. Furthermore those experiments can also be used to distinguish between dissolved and solid salt by using a pore solution with a defined initial concentration.

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