INVESTIGATIONS INTO THE POTENTIAL CONVECTIVE TRANSPORT PROCESS IN MASONRY MATERIALS DEPENDING ON THE MOISTURE CONTENT AND CONCENTRATION OF THE PORE SOLUTION

K. Terheiden[1]

[1]Chair of building chemistry in Civil Engineering, Bauhaus-University Weimar, Weimar, Germany, kristina.terheiden@bauing.uni-weimar.de

ABSTRACT

For the examination of transport processes of deteriorating salts in building materials there are different driving forces that have to be taken into consideration. One is the salt concentration gradient in the pore solution. This concentration gradient may induce two different transport processes: diffusion and free convection. To separate between these two processes and the characteristic initiating conditions, investigations were conducted into the effect of choosing different types of sandstone, different moisture content of the samples and different concentration of the pore solution. The necessary conditions for the occurrence of free convection in porous building materials were the pore radius, the connectivity of the pore system, and the concentration of the salt solution. In some cases a dependence of the moisture content of the specimen on the occurrence of convection was also detected.

KEYWORDS: Convection, diffusion, salt transport, materials

INTRODUCTION

The presence of moisture and salt in the masonry of buildings has several detrimental effects including reducing the quality of living. The presence of deteriorating salts and moisture can invoke aesthetical impairments often followed by partial or full destruction of the building. For the prevention of that endangerment or the revitalisation of contaminated building materials it is necessary to analyse the possible main transport processes. The potential transport processes, which may spread deteriorating salts in buildings, are dependent on the climatic and boundary conditions. However, the variation of these conditions can also be used to invoke a revitalising transport process [1].

These considerations mean that the determination of transport processes is fundamental for the prediction of damaging or revitalising processes. Therefore investigations were carried out into the dominant transport processes occurring under the variation of the moisture content and the concentration of the salt solution. Besides advection, ion diffusion resulting from a concentration gradient has to be taken into consideration. However, by having a concentration gradient there is also a gradient of density, which may lead to convective transport. Therefore it is necessary to determine the conditions under which ion diffusion may give way to convection. By determining diffusive transport coefficients the influencing factors, such as the moisture and salt content and the pore system, on the possible appearance of convection should be detected. Therefore investigations on the conditions for convection and on the appropriate quantification were carried out.

EXPERIMENTAL INVESTIGATIONS

Two different test arrangements were chosen in order to determine the prerequisites for convection in salt and moisture contaminated porous building materials. The difference between [2] and the arrangements used in this work is the separation between pure diffusion and diffusion combined with convection. The schematic arrangements are shown in Fig. 1. Each specimen of the experiment was a composite of two cylindrical samples of different building materials. The cylindrical samples had a diameter of ~ 5 cm and a thickness of ~ 2 cm. One of the cylindrical samples was penetrated with salt solution and the other one with demineralised water. After penetration the cylindrical samples were put together to form one specimen. During the experiment the combined specimens were covered. This prevents the specimen from drying and the appearance of other transport processes.

For the determination of the diffusive transport the cylindrical sample penetrated with the salt solution was placed at the bottom and the one penetrated with demineralised water on top. This arrangement avoids convection caused by gravitation. To initiate possible convection both cylindrical samples were interchanged in position.

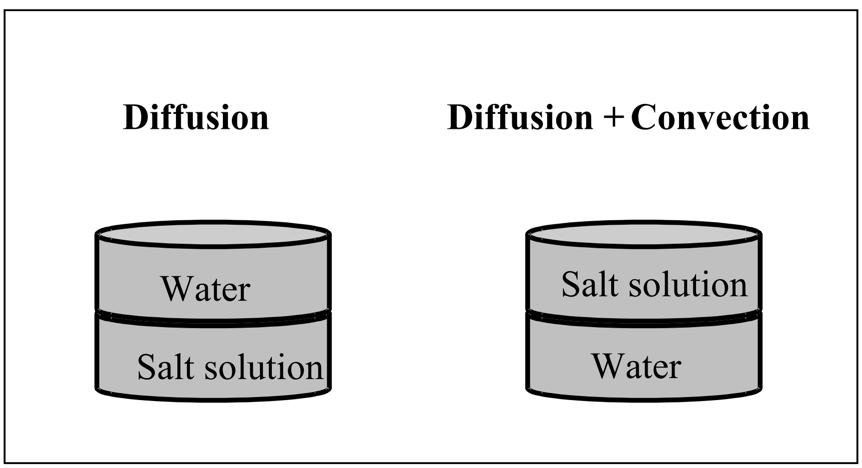

Figure 1 - Experimental Arrangement for the Determination of Diffusion and Convection

To detect the influence of the pore solution concentration on the appearance of convection, 0.5 molar (M), 1.0 molar and 1.4 molar Na_2SO_4-solutions were chosen. The influence of the moisture saturation of the specimen was also investigated by choosing 100 %, 60 % and 30 % saturation. All experimental investigations were done at 25 °C. Four samples for each kind of building material, described later in detail, were examined under the chosen conditions. Furthermore, the transport coefficients were determined from the sodium and sulphate ions.

For the analysis of the experiments, the two cylindrical samples of the specimen were separated after the experiment. Drill powder samples were subsequently taken from each cylindrical specimen varying the depth for the determination of the concentration profiles. By dissolving the salt ions from the powder, the concentration of sodium and sulphate were determined by ICP-OES (Inductively-Coupled-Plasma). Based on the measurements of the concentration profiles over the depth of the specimen, transport coefficients could be determined with the program Win_Diff [3]. The program is based on the solution of Fick´s second law applying finite differences. This software uses the four step Runge-Kutta method for the time-integration [3].

MATERIALS

For the investigations three different sandstones and one brick were chosen. The three sandstones differ in porosity and pore structure as well as in the composition. A description is given in Table 1. The brick is a commercially available material.

Table 1 - Characteristics of the Building Materials

Characteristics	unit	Sandstone 1	Sandstone 2	Sandstone 3	Brick
Pore structure	-	fine-middle grained sandstone	fine-grained sandstone	coarse grained sandstone	commercial
Binder	-	clayey	clayey (ferritic)	siliceous, (clayey)	
Porosity p_0	%	23 ± 1	14 ± 1	24 ± 1.5	31 ± 1
Average pore radius d_{Hg}	µm	8	1.5	36	1

For a more detailed description of the pore structure Fig. 2 shows the pore size distribution determined by mercury intrusion.

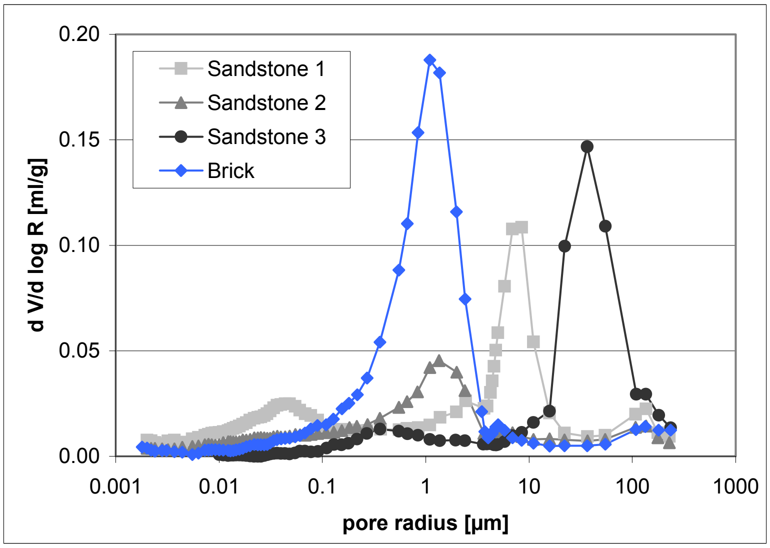

Figure 2 - Pore Size Distribution of the Sandstones and the Brick

The brick has the largest porosity with 31 % whereas sandstone 3 has the largest average pore diameter with 36 µm. Both pore specific parameters may influence the conditions to allow convection in a pore system.

RESULTS

The resulting transport coefficients in the different building materials with their fluctuation are shown in Figs. 3 and 4. Fig. 3 contains the coefficients according to the 0.5 M Na_2SO_4-solution, whereas the results of the specimen penetrated with 1.5 M Na_2SO_4-solution are given in Fig. 4. Both Figures show the transport coefficients of diffusion and diffusion combined with convection.

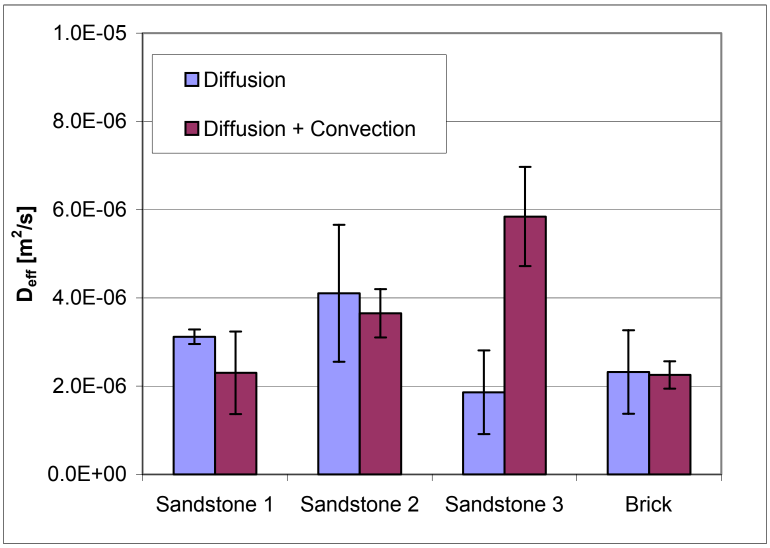

Figure 3 - Effective Diffusion and Transport Coefficients for the Sandstones and Brick At 100 % Moisture Content (0.5 M Na_2SO_4-Solution /Deionised Water)

For sandstone 1, sandstone 2, and the brick, there was almost no difference in the determined effective diffusion coefficients (D_{eff}) related to the two different experimental settings within the range of fluctuation. However, the determined transport coefficients of the sandstone 3 were significantly different. This shows that in this case convection did occur; otherwise the calculated diffusion coefficient would have been the same in both experimental settings.

The same experimental investigations were also performed with a 1.5 M Na_2SO_4-solution. The results are shown in Fig. 4.

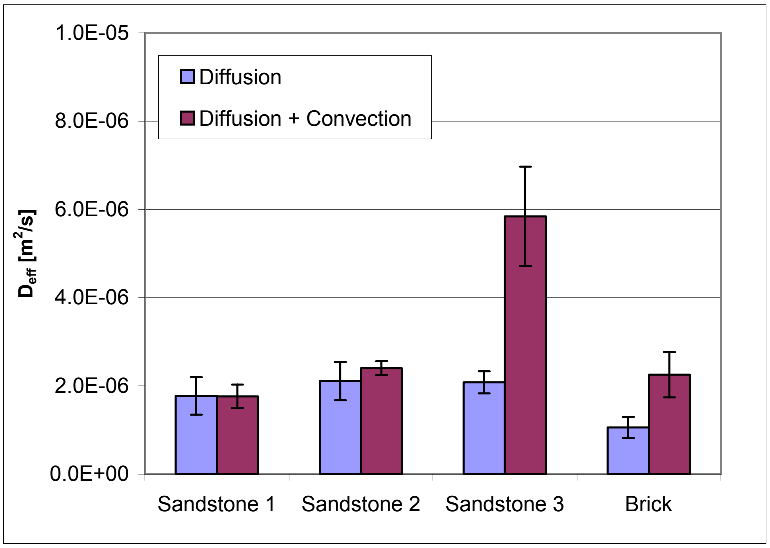

Figure 4 - Effective Diffusion and Transport Coefficients for the Sandstones and Brick At 100 % Moisture Content (1.5 M Na_2SO_4-Solution /Deionised Water)

Comparing the measurements at 0.5 M and 1.4 M, the diffusion coefficients in all materials decreased because of the higher concentration of the pore solution. The transport coefficients of sandstone 1 and sandstone 2 determined under the different experimental settings are again almost equal. Therefore it can be concluded that in these cases no convection occurred.

The brick shows an influence of convective transport with the rising concentration. The transport coefficients of sandstone 3 still show clearly the occurrence of convective transport.

The influence of the moisture saturation on the occurrence of convection was determined in the case of sandstone 3. It was penetrated with 1.0 M Na_2SO_4-solution at moisture contents of 100 %, 60 % and 30 %. In all cases the transport coefficients showed the occurrence of convection. To quantify the influence of the moisture content on the amount of convection Fig. 5 shows the factor of increase of the diffusion coefficient by convective transport.

The determined transport coefficients increase by a factor of about 1.5-2.0. The slight increase of this factor with the lowering of the moisture content is caused by the reduction of the diffusion coefficient and the almost constant value of the convection influenced transport coefficient.

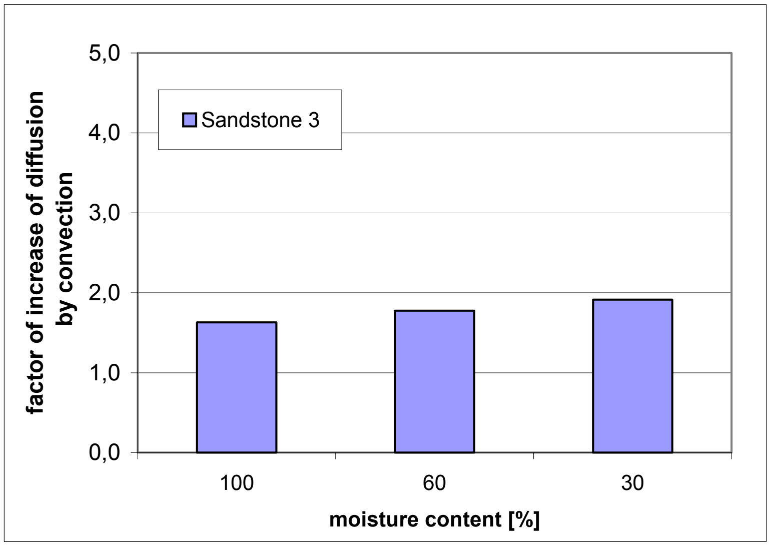

Figure 5 - Factor of Increase for the Diffusion Coefficient (Convective Transport)

SUMMARY
The experiments showed first of all the required conditions of a pore system to allow convection processes to occur. Even at a concentration of 0.5 M Na_2SO_4-solution in the pore system of sandstone 3 a convective transport could be detected. By increasing the concentration up to 1.5 M the brick also showed convective transport. This shows that besides the pore radius the concentration of the pore solution also has a major influence. The sample saturation in the case of sandstone 3 did not result in a significant change in the transport coefficient combined with convection.

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