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# Moisture transport in salt free and salt contaminated ceramic bricks

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**Abstract**

In this work the effect of salt contamination on moisture transport parameters - the water vapor permeability and moisture diffusivity is studied for case of ceramic bricks with very low and low hygroscopic ability. The analysis is focused to small salt concentrations, having practically negligible effect on the material porosity but significantly increasing hygroscopic moisture content of the bricks.

The simply experiment, consisting in monitoring of isothermal one-dimensional capillary uptake and following drying was carried out for salt free and salt contaminated bricks. Tests were done for two different salt concentrations. The moisture uptake and release during the tests was determined by weighting the samples. The experimental results were compared with numerical simulation of the process of drying. In the simulations, desorption curves, measured from capillary moisture content were used as moisture storage functions. Within the hygroscopic range, moisture transport was specified by water vapor permeability, determined from standard cup measurements. Beyond the hygroscopic range, moisture diffusivity function, obtained from absorption coefficient for water and capillary saturation water content, was used for simulation of moisture transport.

On the basis of the comparison, the effect of salt contamination on moisture transport parameters was evaluated. The presence of salt significantly lowered the water vapor permeability by the salt crust formation on the drying surfaces. However, the actual crust formation differed on the particular surfaces and was dependent on the initial moisture content at the surface as well as on the surface roughness.

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## 1. Introduction

A numerical simulation is at present a common tool for determination of a hygro-thermal state of building structures. However, reliable results of numerical simulation can only be obtained on condition of using correct moisture transport and accumulation parameters. Moisture transport and accumulation parameters are commonly measured in laboratory conditions where moisture in material pores is not contaminated. In reality, an interaction between the materials in building structures and chemicals from the surrounding air or water is often present and therefore pore water frequently contains dissolved salt or mixture of different salts.

Drying of salt contaminated porous materials is still poorly understood. This is caused by the complexity of the involved phenomena e.g., moisture and ion transport phenomena and phase transitions. The phenomena of salt efflorescence and the fact that the created salt crust can affect resultant water vapor permeability are generally well known but a quantification of this effect is rarely presented in literature. Significant increase of the water vapor resistance factor value of saline sandstones was reported for example in [1]. Similarly in [2], a decrease of water vapor permeability of ceramic brick contaminated by sodium chloride was detected. However, the extent of the water vapor permeability decrease depended on the actual salt crust formation. A detailed analysis of drying behavior of ceramic brick saturated with the 15 % (kg/kg) sodium chloride solution was presented by Gupta et al. [3], where the drying of saline brick was compared to the standard drying behavior of water saturated materials and significant effect of the actual salt crust properties was found out. Similarly in [4] it was shown that the actual drying rate depends on the type of the created efflorescence.

This work is focused on the effect of salt contamination on the moisture transport parameters - water vapor permeability and moisture diffusivity. Analysis is carried out for two types of ceramic bricks and sodium chloride solutions of small salt concentration, having practically negligible effect on the material porosity. Possible changes of moisture transport parameters were studied by simply experiment, consisting in monitoring of isothermal one-dimensional capillary uptake of distilled water/salt solution and following drying. Based on the comparison of the process in the saline and the salt free specimens and its numerical simulation the effect of salt contamination on moisture transport parameters was evaluated.

## 2. Materials and methods

The tested bricks are commonly used burnt clay brick produced by two different Slovak factories. Basic material parameters (bulk density, total open porosity), water vapor permeability as well as water vapor adsorption isotherms of the salt free and saline (contaminated by 4% NaCl solution) bricks were determined in previous work [2]. Within this work the water vapor adsorption isotherms of bricks, contaminated by 6% NaCl solution and desorption curves were completed.

The water vapor sorption curves were measured by standard gravimetric desiccator method, which consists in conditioning the samples in desiccators under constant RH and temperature (23°C) until the static equilibrium is achieved [5]. The water vapor permeability was measured by the standard cup method [6].

The process of capillary uptake and following drying was monitored on prism samples with the base of ca 34 x 26 mm and the height of ca 52 - 56 mm. The four side surfaces of the specimens were sealed by epoxy resin in order to guarantee one-dimensional (1D) moisture flow. In total, four samples per the same type of brick were tested. Two were immersed into distilled water and two were immersed into 4 or 6% NaCl solution (40 or 60 g of NaCl in 1000 g of distilled water). During the capillary uptake test, the depth of the sample immersion was kept at ca 2 mm. After completion of capillary uptake process, the samples were dried by the air flow (the air flow velocity was between 2.0 - 2.5 m/s) in an air conditioned laboratory room (temperature of $23 \pm 0.5$°C and RH of $53 \pm 1$%). The drying was going on through both of base surfaces of the specimen. Monitoring of the water uptake and release process was done by sample weighing at appropriate time intervals. At the end of tests the samples were oven dried at temperature of 105°C in order to determine actual moisture contents of the samples.

## 3. Results and discussion

Table 1. Basic material properties of salt free and saline bricks D, S.

| Brick | NaCl content [kg/kg] | Bulk density [kg/m³] | Open porosity [-] | Absorption coefficient of water [kg/(m²·s⁰·⁵)] | Capillary saturation moisture content [kg/m³] | Wet cup μ-value [-] |
|-------|------|------|------|------|------|------|
| D3, D4 | 0.0 | 1750 | 0.3 | 0.17 | 230 | 11.0 |
| D1 | 0.005 | 1759 | - | 0.17 | 230 | 9.5 |
| D2 | 0.008 | 1764 | - | 0.16 | 230 | 9.5 |
| S3, S4 | 0.0 | 1460 | 0.43 | 0.33 | 350 | 6.0 |
| S1 | 0.0099 | 1475 | - | 0.31 | 350 | 5.5 |
| S2 | 0.0160 | 1484 | - | 0.31 | 350 | - |

Basic material parameters of the tested bricks D and S are presented in Table 1. The measured adsorption and desorption isotherms are shown in Fig. 2.

The process of capillary water uptake is presented in Fig. 1. As can be seen from Fig. 1, the process of capillary uptake of the samples immersed in salt solutions does not differ from the one of the samples immersed in distilled water. It can be explained by the small concentration of the applied salt solution. As a consequence, practically the same values of absorption coefficient and capillary saturation moisture content were obtained for salt free and saline bricks (Tab. 1).

Fig. 3 presents the monitored process of bricks drying. There was practically no constant drying rate period, as can be expected considering the fact that the drying started from capillary moisture content. In period of the first five or six hours, the rate of drying was similar for all bricks of the same type. Then, the noticeable decrease of the drying rate of the saline bricks compared to the salt free bricks was observed. Simultaneously creating of a salt crust was noticed on the both base surfaces. In case of the bricks D1 and D2, process of the salt crust formation was similar for the both saline samples. It continued up to the 24th hour, when practically continuous salt crust was created on the bases that were in contact with water during capillary uptake test (base 1). The salt crust formed on the bases that was during capillary uptake test in contact with surrounding air (base 2) was thinner and not continuous (Fig. 4). During the whole drying period the drying rate of the both saline bricks D1 and D2 was practically identical.

In case of the S-type bricks an observable salt crust formation continued up to the 30th hour. Similarly to the D-bricks, the salt crust formed on the base 1 was continuous and noticeable thicker than the one formed on the base 2
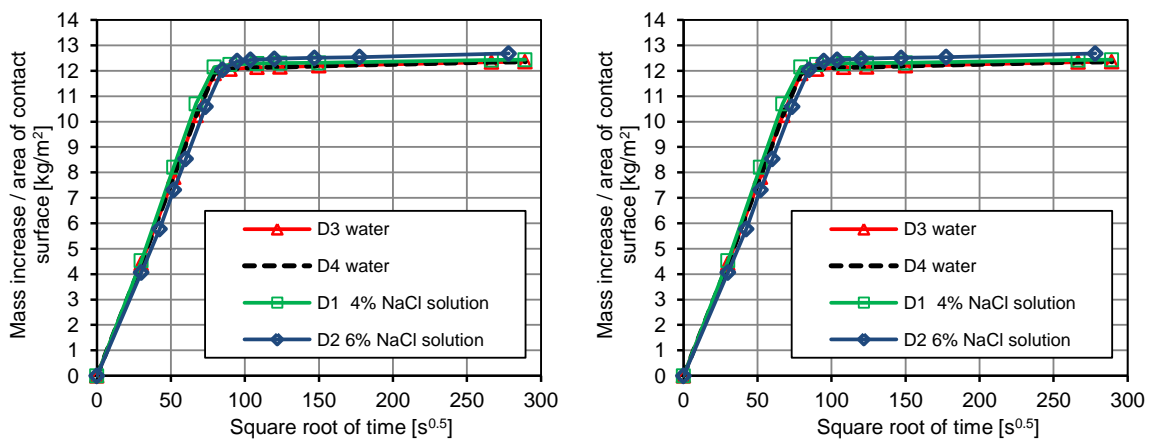


Fig. 1. Comparison of capillary water uptake of ceramic bricks D (left) and S (right) immersed into distilled water or sodium chloride solution of different concentrations.
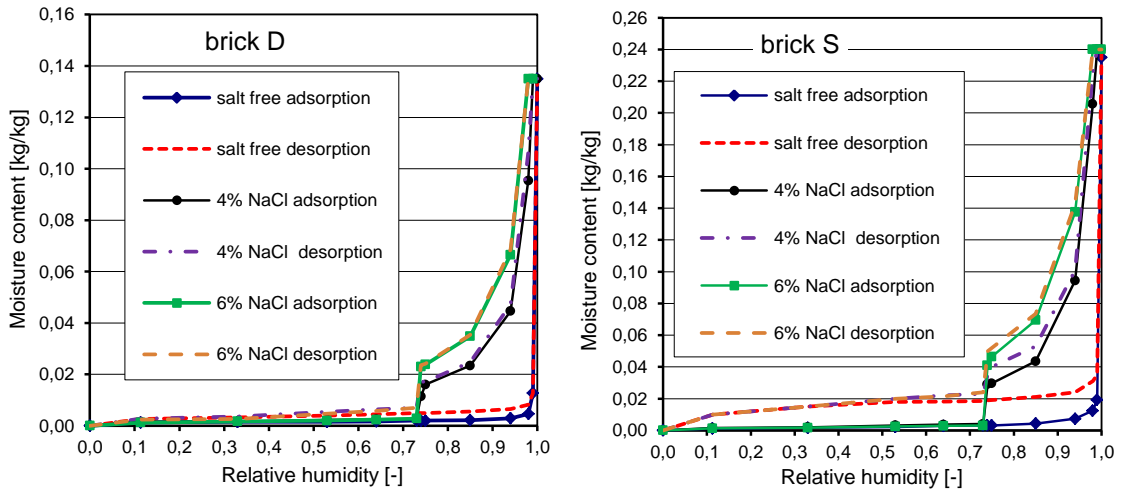
Fig. 2. Water vapor adsorption/desorption loops for salt-free and saline ceramic bricks D (left) and S (right).
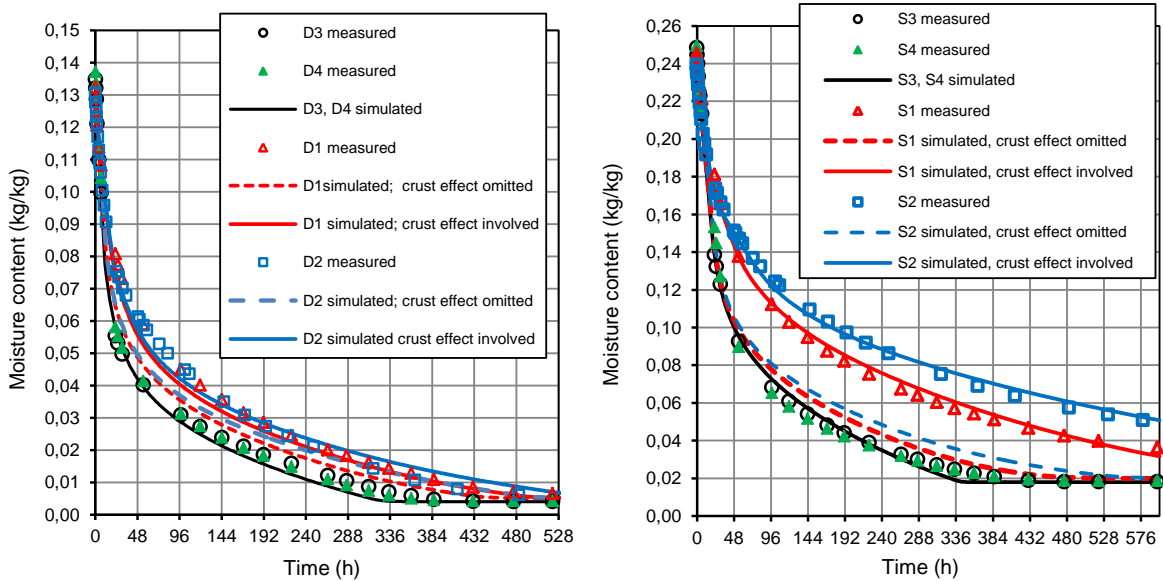


Fig. 3. Process of bricks drying presented by time course of moisture content of the bricks. Comparison of the measured and simulated data. Left: D-bricks (D3, D4 – salt free bricks; D1, D2 – saline bricks). Right: S-bricks (S3, S4 – salt free bricks; S1, S2 – saline bricks).

(Fig. 4). Drying rate of the both saline bricks S was practically the same up to the 30th hour. Then the drying of the brick S2 with the higher salt content was significantly slower (Fig. 4).

The different salt crust formation on particular base surfaces can be explained by the fact that at the beginning of the drying, moisture content was not perfectly identical within the sample and higher moisture content was near base 1, which was in contact with water. Another reason could be the brick non-homogeneity that resulted in presence of coarser surface on the base 2. The second reason is in agreement with results presented in [4] where it was concluded that sufficiently fine porous medium is necessary for creating the crusty (blocking) efflorescence.
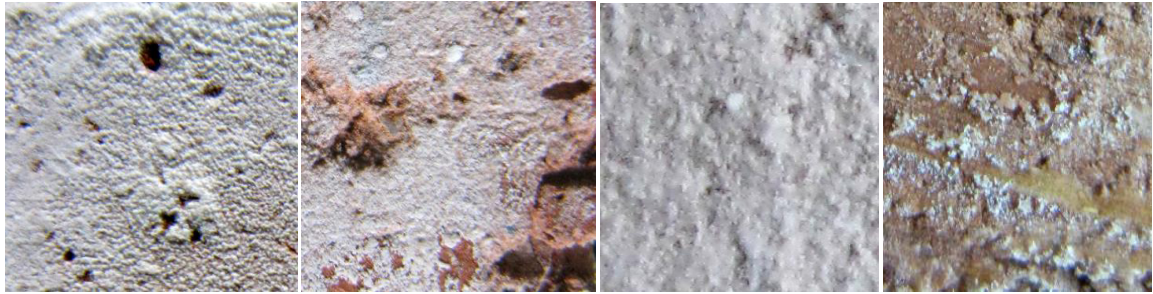
Fig. 4. Efflorescence formed on the brick's bases (from left to right: D1 base1, D1 base2, S2 base1and S2 base2).

Numerical simulations of the 1D drying were done by 1D simulation tool WUFI (version 2.2).

In the simulations, the measured desorption curves (Fig. 2) were used as moisture storage function. Within the hygroscopic range, moisture transport was characterized by water vapor permeability. Beyond the hygroscopic range, moisture diffusivity function was used for simulation of moisture transport.

The moisture dependence of water vapor permeability of salt free and saline bricks D and S was determined in previous work [2]. As follows from this work, in the range of moisture contents, occurring during drying (Fig. 3), the water vapor permeability is practically constant and corresponds to the wet-cup value (Tab. 1).

In evaluation of moisture diffusivity, initially it was supposed that its dependence on moisture content was exponential [7]:

$$D_{\mathrm{w}} = D_{w0} \cdot \exp\left( \frac{w}{w_{cap}} \cdot \log\left( \frac{D_{wcap}}{D_{w0}} \right) \right)$$

$$(1)$$

Where $w$ is moisture content (kg/m$^3$), $w_{cap}$ is capillary saturation moisture content (kg/m$^3$), $D_{w0}$ is moisture diffusivity at moisture content $w_0$ ($w_0$ corresponds to moisture content at the end of hygroscopic range), $D_{wcap}$ is moisture diffusivity at capillary saturation moisture content.

$D_{w0}$ and $D_{wcap}$ were estimated using the measured values of absorption coefficient of water and capillary moisture content [7]. The used moisture diffusivity parameters are summarized in Tab. 2.

For the salt free D-bricks, using the exponential relation (1) in numerical simulation of the drying gave a sufficient agreement with the measured data (Fig. 3). The existing discrepancies can be partly explained by the applied simplification in the evaluation of the moisture diffusivity as well as material non-homogeneity, observable from a small difference between the moisture content courses of brick D 3 and D 4 (Fig. 3). However, for the salt free S-bricks it appeared that the simple relation (1) was not suitable for the process of moisture redistribution. Therefore the moisture diffusivity function was created from four moisture diffusivity/water content values (Tab. 2). Between these values, the moisture diffusivity dependence on moisture content was exponential. Using this function resulted in good correspondence between simulated and measured data (Fig. 3).

In case of saline brick, two simulations were done: Simulation 1 was performed using the material parameters of the saline bricks but with the same moisture diffusivity as for salt free bricks. This simulation was done without involving an effect of salt crust. As can be seen from Fig. 5, an agreement between the simulated and measured results was obtained only for the period of first five /six hours, when the salt crust was not present. In simulation 2

Table 2. The applied parameters of moisture diffusivity.

| Brick | $w_0$ [kg/m$^3$] | $D_{w0}$ [m$^2$/s] | $w_1$ [kg/m$^3$] | $D_{w1}$ [m$^2$/s] | $w_2$ [kg/m$^3$] | $D_{w2}$ [m$^2$/s] | $w_{cap}$ [kg/m$^3$] | $D_{wcap}$ [m$^2$/s] |
|---|---|---|---|---|---|---|---|---|
| D3, D4 | 80 | $2 \cdot 10^{-9}$ | - | - | - | - | 230 | $2 \cdot 10^{-7}$ |
| D1, D2 | 90 | $2 \cdot 10^{-9}$ | - | - | - | - | 230 | $2 \cdot 10^{-7}$ |
| S3, S4, S1, S2 | 80 | $1 \cdot 10^{-10}$ | 140 | $1.3 \cdot 10^{-10}$ | 160 | $3.0 \cdot 10^{-9}$ | 350 | $3.4 \cdot 10^{-7}$ |

Table 3. Additional water vapour resistances on sample bases expressed as water vapour diffusion equivalent air layer thickness ($s_d$)

| Bricks D1, D2 | | | Brick S1 | | | Brick S2 | | |
|---|---|---|---|---|---|---|---|---|
| Period of drying [h] | $s_d$ (base 1) [m] | $s_d$ (base 2) [m] | Period of drying [h] | $s_d$ (base 1) [m] | $s_d$ (base 2) [m] | Period of drying [h] | $s_d$ (base 1) [m] | $s_d$ (base 2) [m] |
| 0 – 5 | 0 | 0 | 0 – 6 | 0 | 0 | 0 – 6 | 0 | 0 |
| 6 – 24 | 0.008 | 0.002 | 7 – 19 | 0.025 | 0 | 7 – 19 | 0.025 | 0 |
| from 24 | 0.02 | 0.01 | from 24 | 0.12 | 0.006 | 20 - 30 | 0.15 | 0.003 |
| | | | | | | from 31 | 0.25 | 0.012 |

the same material parameters were applied as in simulation 1, but the crust effect was involved by considering of an additional water vapor resistances on sample bases (Tab 3). Here, the continuous process of the creating of salt crust was evaluated by a simplified way, using constant values for the particular period of drying. As can be seen from Fig. 3, this procedure gave satisfactory agreement between the measured and simulated data in case of S-bricks. However, in case of D-bricks the matter was not so straightforward. Using the moisture diffusivity of the salt free bricks resulted in significant overestimation of the drying rate. The possible reason could be that the used exponential relation did not correspond to the actual moisture diffusivity at the process of moisture redistribution. This fact was not significant for salt-free brick with negligible hygroscopicity but became important for saline brick with different sorption curve (Fig. 2). Another reason could be that only a part of the water bound by salt contributed to the capillary moisture transport. Therefore in the evaluation of moisture diffusivity (Eq. 1) a modified value of $w_0$ (cf. Tab. 2) was applied. Then the more acceptable agreement between the simulated and measured data was obtained.

## 4. Conclusions

An effect of the low salt contamination on parameters of the moisture transport was studied for case of two types of burnt clay brick with low hygroscopic ability. The measurements have shown that for the low salt concentrations the process of capillary uptake is practically identical for the bricks immersed into salt solution and the ones immersed into distilled water. The process of drying is significantly affected by actual salt crust creation. For the tested salt concentration, the water vapor as well as capillary water transport within the brick was only slightly affected by presence of salt. The lowering of water vapor permeability can be fully explained by presence of salt crust formed of sample surface. The salt crust formation was affected by initial moisture content at the surface. It is probable that the surface roughness could have some effect as well.

## Acknowledgements

## References

[1] Kiessl K. Bauphysikalische Einflüsse bei der Krustenbildung am Gestein alter Bauwerke. *Bauphysik* 11(1989): 44-49.
[2] Koronthalyova O, Bagel L, Kuliffayova M & Ifka T. Effect of presence of salt on hygric performance of burnt clay bricks. *Transp Porous Med,* Vol. 107(2015): 667-682.
[3] Gupta S, Huinink HP, Prat M, Pel L & Kopinga K. Paradoxical drying of a fired-clay brick due to salt crystallization. *Chem Eng Sci*, Vol.109 (2014): 204-211.
[4] Eloukabi H, Sghaier N, Ben Nasrallah S & Prat M. Experimental study of the effect of sodium chloride on drying of porous media: The crusty–patchy efflorescence transition. *Int J Heat and Mass Tran*, Vol. 56(2013): 80-93.
[5] EN ISO 12571:2000 Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties.
[6] EN ISO 12572:2001 Hygrothermal performance of building materials and products - Determination of water vapour transmission properties.
[7] Kunzel, HM. Simultaneous Heat and Moisture Transport in Building Components, IRB Verlag Stuttgart 1995, ISBN 3-8167-1403-7.