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SIMPLE METHODS TO APPROXIMATE THE LIQUID TRANSPORT COEFFICIENTS DESCRIBING THE ABSORPTION AND DRYING

Martin. Krus, Dr.-Ing.; Andreas Holm, Dipl.-Phys.; *

1. INTRODUCTION

For transient calculations of moisture behaviour with new calculating methods, additional parameters are sometimes necessary in order to be able to achieve good correspondence between calculations and measurements. Liquid transport exercises a particular influence on moisture behaviour. Per unit of time, it can transport tens of times more water inside materials than diffusion. The correct determination of the transport coefficients for liquid transport is thus of decisive importance. As discussed in [1], a distinction must be made between wetting and drying, i.e. these two boundary conditions produce different liquid transport coefficients. The determination of these transport coefficients, which are highly dependent on water content, is made possible by the measurement of water-content profiles in the building material using an apparatus based on nuclear-magnetic resonance or on γ radiography [1, 2]. Such precise but time-consuming and cost-intensive determination is, however, often not absolutely necessary. For this reason it would be desirable to have procedures permitting good approximations for the liquid transport coefficients of the wetting and drying processes to be obtained from basic hygric parameters already known for most building materials or from simple additional experiments.

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* Fraunhofer Institute for Building Physics, (Director: o. Prof. Dr.-Ing. habil. Dr. h.c. mult. Dr. E.h. mult. Karl Gertis), Fraunhoferstr. 10, D-83626 Valley, Germany

2. **PRINCIPLES**

For capillary transport, Krischer [3] has introduced the following diffusion equation:

$$g_W = -D_W(u)\frac{du}{dx} \tag{1}$$

g_W [kg/m^{2}s]	Liquid transport flow density
$D_W(u)$ [m^2/s]	Liquid transport coefficient
u [Vol.-%]	Water content

In his theoretical derivation Krischer assumes a capillary bundle model consisting of parallel cylindrical capillaries of varying diameter interconnected without any resistance. Equilibrium of pressure in all filled capillaries at a given cross section of the bundle is assumed. The negative pressure in the liquid is then determined by the capillary suction of the taut meniscus of the largest still-filled capillary in this cross section. This relationship between the capillary suction stress in a cross section of the bundle and the water content there results in a capillary transport coefficient D_W which is strongly dependent on water content

Absorption (before cutting supply) Redistribution (after cutting supply)

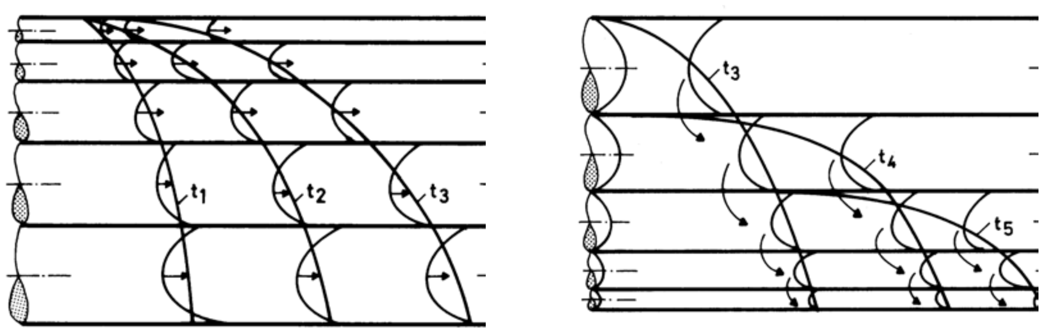

Fig. 1: Capillary transport phenomena represented by a model of interconnected cylindrical capillaries of various diameters.

If the supply of water is cut off, ongoing fluid transport takes place, although counter-menisci do form on the surface no longer supplied with water (see Fig. 1, right). This subsequent movement of fluid occurs because the smaller pores not yet filled suck dry the larger filled pores through the cross-connections by virtue of their greater suction power. It is anticipated that this ongoing movement of fluid proceeds much more slowly than does the transport during the absorption process, so that it is necessary to apply different fluid transport coefficients depending on the boundary conditions (wetted or unwetted surface).

3. TRANSPORT IN THE HYGROSCOPIC MOISTURE RANGE

In the hygroscopic moisture range, the water content of a building material is described by sorption isotherms. In the range below approx. 50% rel. humidity, the water molecules are bound so strongly to the pore walls that noticeable liquid transport can be excluded. Above 50% RH, capillary condensation occurs in the micropores. For most building materials the vapour-diffusion resistance determined for the moist range measured in accordance with DIN 52615 is attributable to liquid transport in this moisture range which is superimposed on diffusion [4]. If the sorption isotherms for the hygroscopic moisture range are known, the capillary transport coefficients can be calculated from the difference between the mass flows measured in the higher air humidity range and those measured in the dry range[1]. The liquid transport coefficients determined in this way are listed for a number of building materials in Table 1.

Table 1 Liquid transport coefficients at hygroscopic moisture content determined from isothermal diffusion [1]. Knowledge of the sorption isotherms is necessary for calculation.

Material	Average sorption moisture content [Vol.-%]	Liquid transport coefficient D_{wo} [m^2/s]
Baumberger	3.1	$2.5 \cdot 10^{-10}$
Obernkirchner	0.27	$1.9 \cdot 10^{-10}$
Rüthener	1.1	$2.9 \cdot 10^{-10}$
Sander	1.8	$1.8 \cdot 10^{-10}$
Gypsum	0.71	$3.5 \cdot 10^{-10}$
Lime silica brick	2.4	$1.8 \cdot 10^{-10}$
Aerated concrete	4.4	$1.1 \cdot 10^{-10}$
Brick	0.29	$2.6 \cdot 10^{-10}$

As will be seen from this table, all the materials listed exhibit almost the same hygroscopic transport coefficient of approx. $2 \cdot 10^{-10}$ m²/s. This is not surprising when one considers that under these conditions in all the samples the pores are filled with water up to the same maximum pore radius. There should thus also be a comparable capillary transport coefficient. It therefore seems sensible, for approximation purposes, to fix the capillary transport coefficient in the hygroscopic moisture range at $2\cdot10^{-10}$ m^2/s. As the water content of most building materials is often known at 80% , it is sensible to attribute this transport coefficient to u_{80}. For the approximation of the capillary transport coefficient this gives a function which, for u_{80}, begins with a value of $2\cdot10^{-10}$ m^2/s. As a distinction between absorption and redistribution does not appear to be physically meaningful in the hygroscopic moisture range, where liquid transport takes place in the sorbate film, this value applies to both transport processes.

4. EXPONENTIAL APPROXIMATION

For most building materials, the capillary transport coefficient can be approximated quite satisfactorily with an exponential function [1, 5]:

$$D_w(u) = D_{wo} \exp\left(\frac{u}{u_f} \ln \frac{D_{wf}}{D_{wo}} \right) \qquad (2)$$

D_{wf} [m²/s]	Transport coefficient at capillary saturation
D_{wo} [m²/s]	Transport coefficient in the sorption moisture range

4.1 Absorption process

For the absorption process, the following relationship between D_{wf} and the A-value can be derived [6]:

$$D_{wf} = \frac{K \pi A^2 \ln(D_{wf} / D_{wo})}{4u_f(u_f - u_{80})} + D_{wo} \qquad (3)$$

u_f [kg/m³]	Capillary saturation water content
u_{80} [kg/m³]	Sorption water content at 80% RH.
D_{wo} [m²/s]	Transport coefficient in the sorption moisture range ($2\cdot10^{-10}$ m²/s independent of material)
K [-]	Correction factor

Equation (3) is represented in Fig. 2, so that if the A-value, the capillary saturation and u_{80} are known, D_{wf} can also be determined graphically in a simple way.

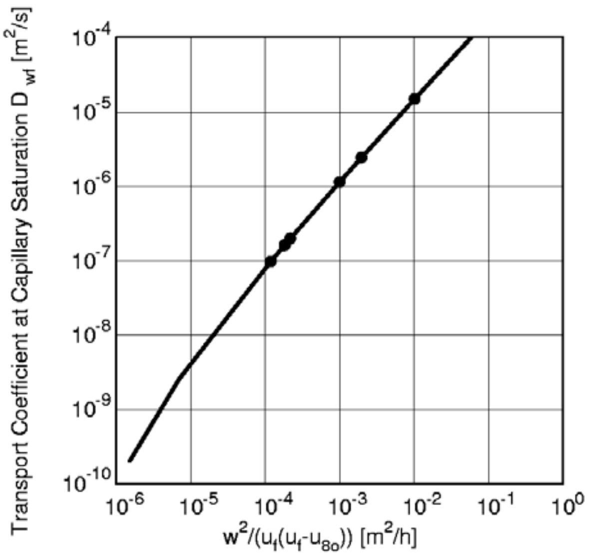

Fig. 2 Representation of Equation (3) for the graphical determination f D_w. The values for the materials listed are marked as dots.

4.2 Drying process

By analogy to the determination of the water absorption coefficient, the observation of the drying behaviour of an experimental sample that was originally saturated should provide information about the transport coefficients for the redistribution or drying process. According to Krischer [3], the drying of a water-saturated, porous building material can be divided into various drying stages. As long as capillary transport is great enough to carry a sufficient amount of water to the surface, under constant external climatic boundary conditions the evaporation from the surface must remain virtually constant. During this first drying stage, the drying speed only depends on the external conditions; the characteristics of the building material have no influence. As capillary transport in the building material becomes greatly reduced with the decrease in water content, the amount of liquid transported to the surface will, at a definite point of time, not suffice to maintain the initial drying speed. The result is that, at this drying stage, a constantly sinking drying speed is observed. Here the course of drying is dependent not only on climatic conditions but also on the diffusion resistance factor and the liquid transport coefficients for redistribution.

For determining D_{ww} by calculation, the Heat and Moisture Simulation Program WUFI [7], which has already been verified in many applications, is employed. Any other comparable calculation program using moisture-dependent capillary transport coefficients may, of course, also be used. In determining the transport coefficients for the redistribution process, the measured and calculated weight courses are compared with one another. Two steps must be carried out. Firstly the heat transfer coefficient present on the evaporation surface must be determined. To do this, WUFI's default value of 8 W/m²K is increased - in a climatic chamber, ventilators are always used - until the courses calculated for the weight in the first drying stage correspond to the measurements. As the second step, the transport coefficient D_{ww} at capillary saturation is adapted until a minimum deviation between the calculated and the measured course results for further drying, too. With a little practice, quite good correspondence can be achieved after only two to four calculation runs (approx. 2 mins. calculating time each).

5. RESULTS

Table 2 shows the approximated transport coefficients for the absorption and drying processes achieved by the methods described for a selection of building materials. Fig. 3 compares the distributions calculated for the absorption process with the help of the approximated transport coefficients and the measurements. Fig. 4 shows a similar comparison for the water-content course during drying.

Table 2 Basic hygric parameters and subsequently calculated exponential approximations of the liquid transport coefficient at capillary water saturation. For the transport coefficients at u_{80}, a value of $2 \cdot 10^{-10}$ m²/s is fixed.

Material	Reference moisture content u_{80} [Vol.-%]	Capillary saturation u_f [Vol.-%]	Water absorption coefficient w [kg/m²h$^{0.5}$]	Transport coefficient Absorption $D_{ws}(uf)$ [m²/s]	Transport coefficient Drying $D_{ww}(uf)$ [m²/s]	Relation D_{ws}/D_{ww} [-]
Baumberger	3,6	21	2,6	$2{,}25 \cdot 10^{-7}$	$1{,}1 \cdot 10^{-7}$	2
Obernkirchner	0,28	9	2,8	$1{,}15 \cdot 10^{-6}$	not determ.	-
Rüthener	1,2	18,5	18	$9{,}7 \cdot 10^{-6}$	$3{,}2 \cdot 10^{-6}$	3
Sander	1,9	12	1,2	$1{,}24 \cdot 10^{-7}$	$4{,}13 \cdot 10^{-8}$	3
Lime silica brick	2,5	25	3,2	$3{,}14 \cdot 10^{-7}$	$6{,}3 \cdot 10^{-8}$	5
Brick	0,31	34	15	$5{,}38 \cdot 10^{-6}$	$3{,}58 \cdot 10^{-6}$	1,5
Gypsum plaster	0,79	35	5,1	$2{,}00 \cdot 10^{-7}$	not determ.	-

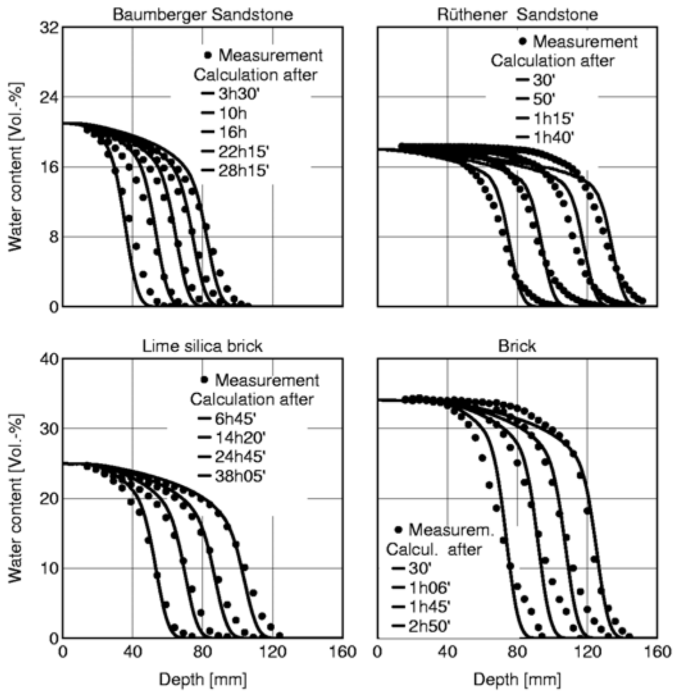

Fig. 3 Water content distributions over the depth of various building material samples at various times on the basis of NMR measurements and calculations of the absorption process.

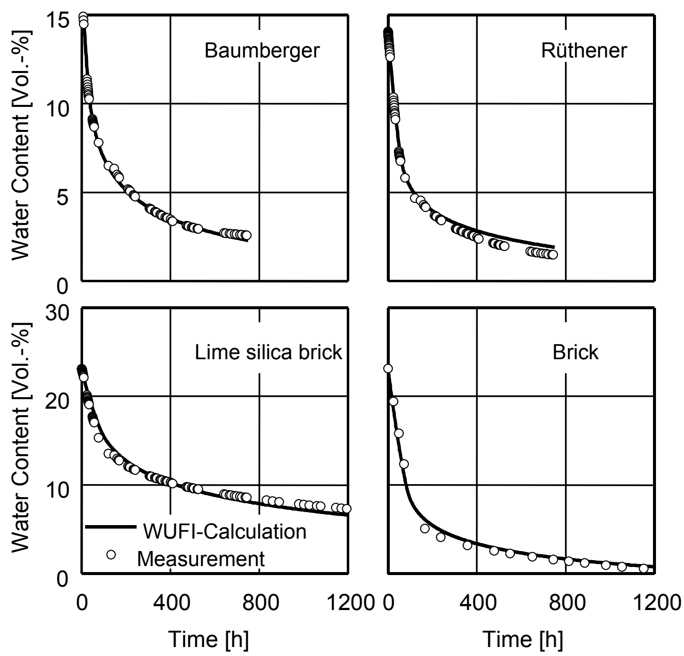

Fig. 4 Course of drying of initially saturated samples with one-sided drying at 20°C and 65% RH. The measured results are presented as dots, the calculated ones as a solid line.

6. SUMMARY

Computer calculations are of increasing importance for the assessment of moisture balance in building components, since modern calculation methods achieve good agreement with measurements. A broader application of these methods is hampered, however, by the laborious measurements needed to determine the capillary transport coefficients essential for the calculations. A new method is therefore presented which allows to estimate the coefficients of water absorption from well-known standard material properties (free capillary saturation, practical moisture content and water absorption coefficient). The drying process mostly shows significantly smaller liquid transport coefficients. A new method is also presented to determine approximately these coefficients from results of a simple drying experiment. A comparison of calculated results using these approximations and exactly determined coefficients shows only moderate and acceptable deviations from reality. (The procedures to get the approximated coefficients are implemented in a calculation program, which can be ordered for free via Internet (http://www.hoki.ibp.fhg.de)).

7. REFERENCE

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