FREE-WATER INTAKE OF CELLULAR CONCRETE AND BRICKS

MEASURED BY GAMMA RAY ATTENUATION

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1. Introduction

Free-Water intake tests have been made very often as it is an easy test method. A specimen is taken, put in water and the moisture content is found by being weighed at certain times. The results of such a test are not very interesting as building materials seldom are placed in contact with free water.

It is however possible to get much more information from this type of experiment if the moisture distribution is known at certain times. Then it is possible to calculate the moisture diffusivity dependence of the moisture content. This knowledge of the moisture diffusivity could be used for calculations of moisture transfer as drying, driving rain and so on.

2. Theory.

The moisture transfer in a long specimen takes place after the differential equation:

$$(1) \quad \frac{\partial \psi}{\partial t} = \frac{\partial}{\partial x}\left(D \frac{\partial \psi}{\partial x}\right)$$

where ψ is the moisture content (m^3/m^3)
t is the time (h)
x is the place (m)
D is the moisture diffusivity (m^2/h)

We assume that the gravitational constant has no influence as the experiments only last a short time. Further we assume that the specimen at start has uniform moisture distribution ψ_i (could be laboratory conditions 20° and 50 RH). The saturation moisture content ψ_s is assumed to be constant. The experiment is done this way:

(2) $\psi\ (x,t) = \psi_i$ for $x > 0,\ t = 0$

(3) $\psi\ (x,t) = \psi_s$ for $x = 0\quad t > 0$

The nonlinear partial differential equation (1) cannot be solved by usual methods. Boltzmann transformation could be used to form an ordinary differential equation. To make the transformation we let ψ be given as

(4) $\psi = f\ (\lambda)$

where λ is a function of x and t, defined by

(5) $\lambda = x \cdot t^{\frac{1}{2}}$

Equation (5) is called the Boltzmann transformation. To solve the equation (1) we need a third condition:

(6) $\frac{\partial \psi}{\partial \lambda} = 0$ for $\psi = \psi_i$

And by using an evalution from Kirkham and Powers [1] we find:

(7) $$D(\psi_x) = \frac{1}{(\partial\psi/\partial\lambda)_{\psi_x}} \left(-\tfrac{1}{2}\right) \int_{\psi_i}^{\psi_x} \lambda\, d\psi$$

This calculation method could only be used for finite length of specimen if the moisture front is not affected at the end of the specimen. Equation (7) has been used on cellular concrete (the point marked by symbols on fig. 4).

We normally use another method described in Vachaud [5], where it is only assumed that the moisture transfer follows the equation

(8) $$q_m = - D(\psi) \cdot \rho \cdot \frac{\partial \psi}{\partial x}$$

where q_m is the density of mass flow rate (kg/m^2h)

ρ is the density of water (kg/m^3)

If we have 3 moisture distributions at certain times it is possible to calculate the mass flow rate and the gradient in moisture content, and from that to find the moisture diffusivity.

3. Gamma-Ray Measurements

The method of gamma-ray-attenuation has been used for determination of the moisture content. These measurements are non-destructive, but require a calibration on the used material.

The Laboratory of Thermal Insulation has an equipment [2] with a 1oo mCi Am-241 source with 6o keV gamma-ray emission. The detector is a gamma scintillation detector with NaI. The source and the detector have collimators to give a beam of about 5 mm in height and 1o mm in width.

The measurement of the moisture content is always made in the same place in the specimen in order to avoid problems of inhomogeneity. It is necessary to determine the intensity of the beam in the dry material first to get the zero values of moisture content in the places of measurement. It is then possible to measure the intensity variations of the beam from the zero value and to find the moisture content from:

(9) $$\psi = \frac{\ln N_o - \ln N_z}{\mu \cdot x \cdot \rho}$$

where ψ is the moisture content (m^3/m^3)

μ is the absorption coefficient for water (m^2/kg)

ρ is the density for water (kg/m^3)

x is the concrete thickness (m)

N_o is the intensity with no water (counts/s)

N_z is the intensity with water (counts/s)

The absorption coefficient of water is found to be dependent on water content. Therefore a calibration must be made.

We use a fixed time of 1.4 min. per measurement. With this value, the standard deviation for moisture content is found for 5%vol ± o.2%vol, and for 6o%vol ± o.5%vol for cellular concrete.

4. Experimental and calculation methods.

The free-water intake was realized by placing the specimen app. 1 mm in water. The specimen had insulated sides (diffusion teight tape). The size of the specimens were:

1. Cellular concrete cylindrical height 15 cm diameter 12 cm.
2. Bricks app. height 22 cm, width 12 cm, thickness 5.2 cm.

The experiments were continued until the moisture front had reached the end of the specimen.
The gamma-ray measurements were done automaticly with one scan through the specimen every half hour. The measurements were done in 15 heights, 5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135 and 145 mm from the immersed end of the specimen. As each measurement took 1.4 min. it gives a good accuracy on the moisture content. All the data from the experiments were punched on papertape. From this the moisture content was calculated from equation (9) as the intensity with no water was calculated first from the first scan, where the moisture content was 1% vol for bricks and 2% vol for cellular concrete.

Then we have a series of data in the form of point values of the moisture content at certain height and at certain hours. To use the calculation method of Vachaud [5] it is necessary to have smooth curves of the moisture distribution at certain times. Such curves were created from the original data by using spline-function of third degree. These spline-curves give a good approximation of the moisture distribution as they would fit very well to the measured points without any knick-points. From this spline-curve the moisture diffusivity in depencence of the moisture content is calculated. The computer program is also made, so that it is possible to make calculation only for certain height intervals.

In this way it should be possible to find if there is any difference in the moisture diffusivity from inhomogeinities in the specimen.

All the computer calculations have been run on IBM 370/165 at NEUCC, and the results were plotted with a Calcompplotter.

5. Cellular concrete.

The moisture distribution during free-water intake in cellular concrete is found on fig. 1. Each curve shows the statistical variation of the gamma-rays, and as it is seen the variation is rather small. This data was used to calculate the absorption coefficient and the knick point moisture content (Table 1).

The curves of fig. 1 were also used to calculate the moisture diffusivity by the methods of Vachaud [5]. Fig. 2 gives the diffusivity for heights (3-6 cm) from the free water surface. The spread out of the curves gives an impression of the variations in the moisture diffusivity. These variations could be caused by inhomogeneities, measurement inaccuracy and calculation inaccuracy. It has not been possible to find out which of these inaccuracies there is the most important. If that was known it should be possible to get better results. Fig. 3 shows the moisture diffusivity for the height (6-9 cm). The results have the same variations as in fig. 2, and the values are alike. More experiments have been made on cellular concrete but all the values are like these. It could be pointed out that the variation is a factor 10 at 10%vol and only 2 at 25%vol. This must be caused by the gradient being much better defined at 25%vol.

Fig. 4 shows the moisture diffusivity found from drying experiments (Nielsen [3] [4]). This curve fall is in the same area as the free-water intake test, and from that we would conclude that it is possible to use the diffusivity from free water-intake for calculations of drying. The points marked by symbols are calculated from equation (7). Each symbol is a certain specimen. These points are in good accordance with both the earlier calculations (fig. 2 and 3) and the drying experiments.

6. Sand-lime bricks.

The moisture distribution in sand-lime brick is found on fig. 5. The free-water intake on sand-lime brick takes much more time, app. 80 hours before the moisture front has reached 15 cm up in the brick. The statistical variations of the measurements are caused by the higher density. After 140 hours it is found that there is still a variation of 5%vol from the lower till the upper part of the brick. This could be caused by gravitation. The moisture diffusivity of sand-lime brick is found in fig. 6. The curves are of a similar type as the ones of cellular concrete with higher values at high moisture content. The absorption coefficient is found in table 1.

7. Moler brick.

This type of brick consist of moler and is used as an isolant brick for high temperatures. The free-water intake test shows (fig. 7) that the maximal moisture content is app. 60%vol. and the intake is very fast. This is also found in the absorption coefficient (table 1). Fig. 8 gives the moisture diffusivity.

8. Bricks Type A and B.

This is two types of bricks with a density of 1775 kg/m^3 (A) and 2025 kg/m^3 (B). Fig 9 and 11 give the moisture distribution. It is found that the water front moves very fast through these types of bricks and makes the results of the moisture diffusivity calculation more uncertain. As it was expected the lower density brick (A) absorbs more water than the high density brick (B). From these curves the absorption coefficient could be calculated and it is found in table 1.

The moisture diffusivity is found on fig. 10 and 12. The only curve on fig. 12 is badly defined, as the moisture flow goes rather fast.

9. Conclusion.

The results of these experiments are only the first in a series of free-water intake on building materials. The idea is to find an easy way to find the moisture diffusivity for building materials as they are used in practice. Therefor the experiments on bricks will be performed on normal bricks without any sorting procedure.

The article gives a short description of the theory and calculations for free-water intake experiments. Special attention is drawn on the gamma-ray measurement method. Then some experiments and results on different types of materials are shown. The most interesting thing is maybe the calculation of the moisture diffusivity in dependence of the moisture content.

Table 1.

	density kg/m^3	moisture content m^3/m^3 *	absorption coefficient $kg/m^2\ sek.^{\frac{1}{2}}$
Cellular concrete	570	28,4	0,082
Sand-lime brick	1950	17,7	0,042
Moler brick	790	55,4	0,471
Brick A	1775	25,6	0,233
Brick B	2025	10,5	0,175

* moisture content at knick point.

References:

[1] Kirkham, D., and Powers, W.L.: Advanced soil Physics Wiley - Interscience 1972, ISBN 0471-48875-5.

[2] Nielsen, A.F.: Gamma-Ray-Attenuation Used for Measuring the Moisture Content and Homogeneity of Porous Concrete. Building Science. Vol. 7, pp 257-263, 1972.

[3] Nielsen, A.F.: Moisture Distributions in Cellular Concrete during Heat and Moisture Transfer. Licentiate Dissertation. Thermal Insulation Laboratory, Technical University of Denmark, 1974

[4] Nielsen, A.F.: Drying of cellular Concrete. Thermal Insulation Laboratory, Technical University of Denmark 1975. Medd. nr 39.

[5] Vachaud, G.: Thesis at the school of Science of the University of Grenoble, France 1968.

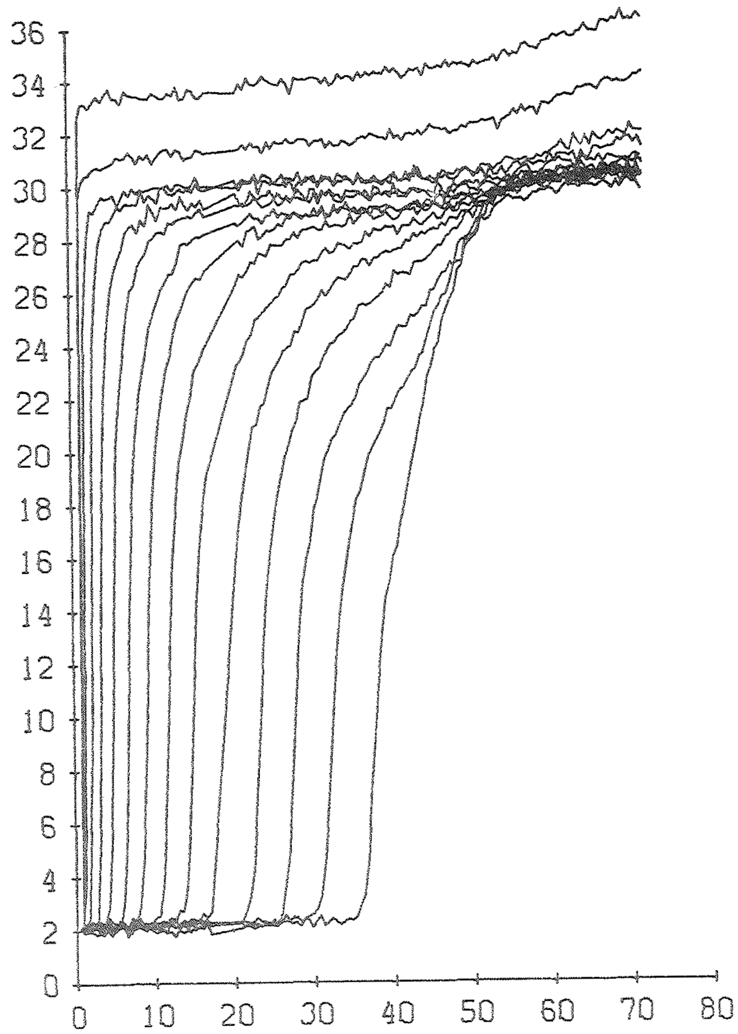

Fig. 1. Moisture distributions in cellular concrete (570 kg/m^3) during free-water intake. Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

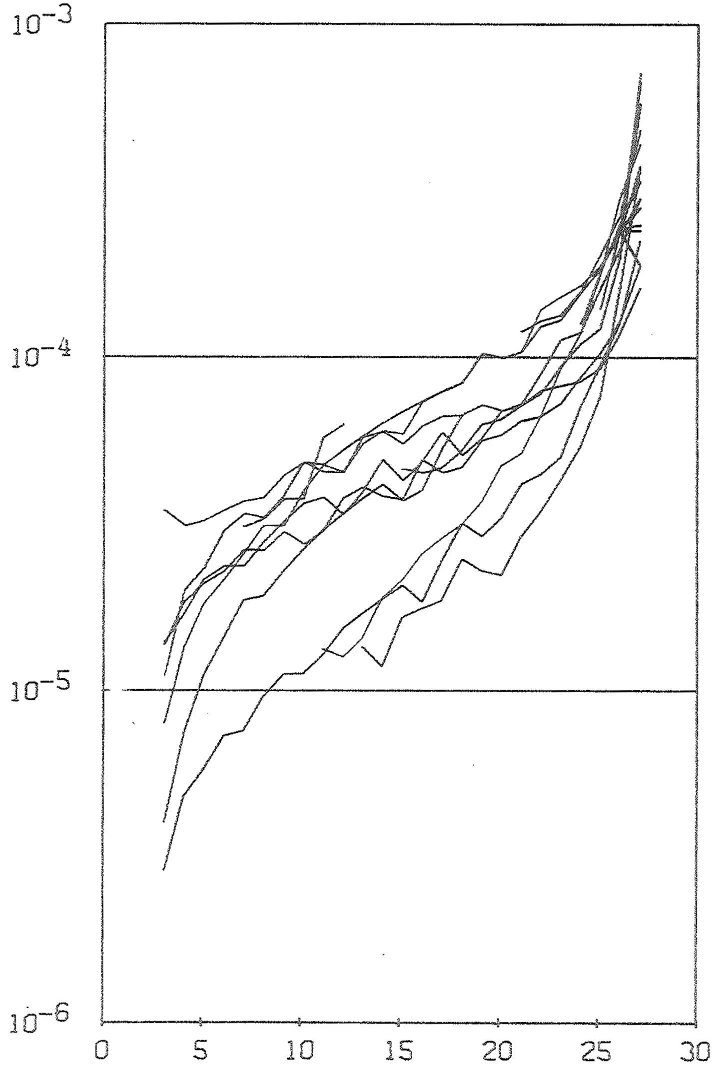

Fig. 2. Moisture diffusivity for cellular concrete (570 kg/m^3) calculated from free-water intake. Height 3-6 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

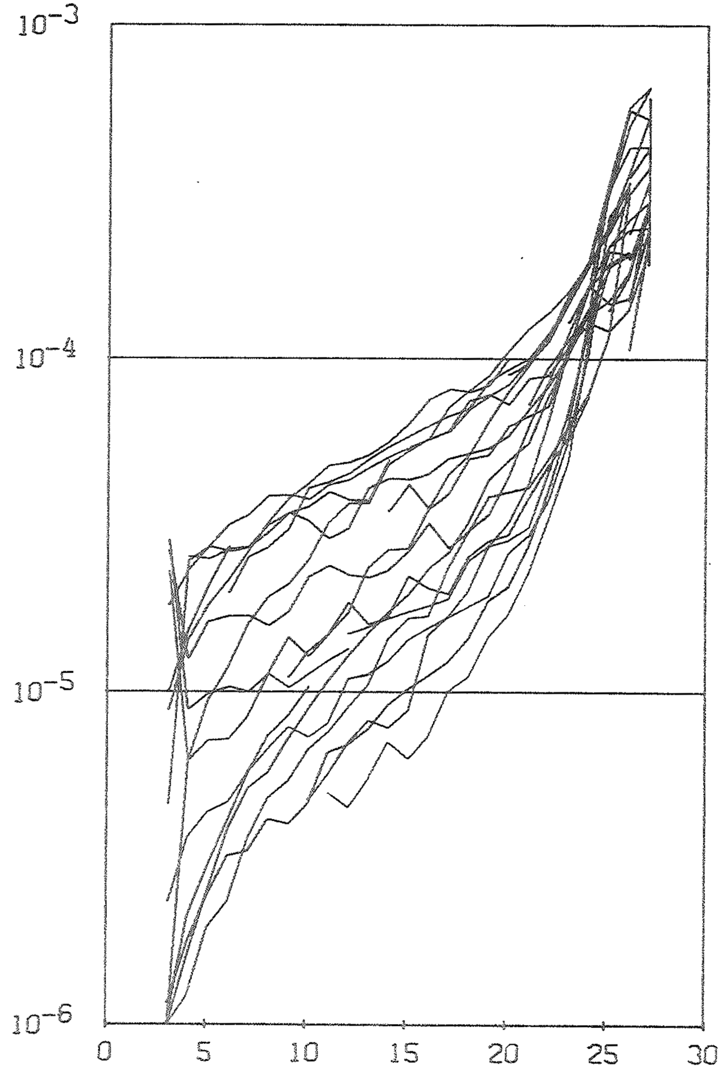

Fig. 3. Moisture diffusivity for cellular concrete (570 kg/m^3) calculated from free-water intake. Height 6-9 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

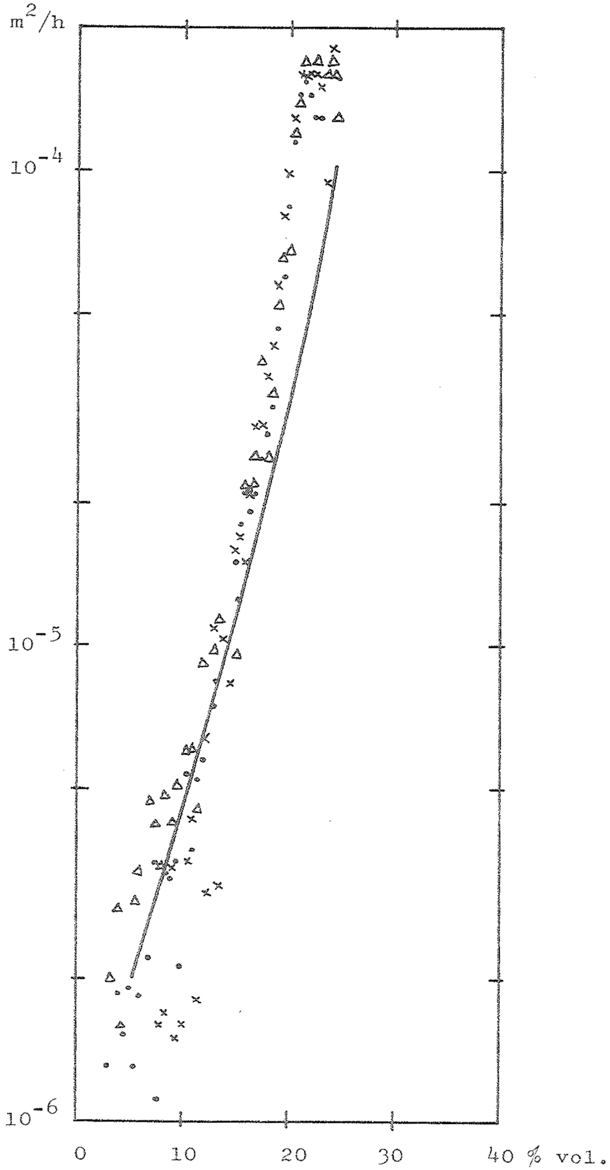

Fig. 4. Moisture diffusivity for cellular concrete calculated from free-water intake by another method. Results marked by symbols. The solid line shows the results from drying experiments.

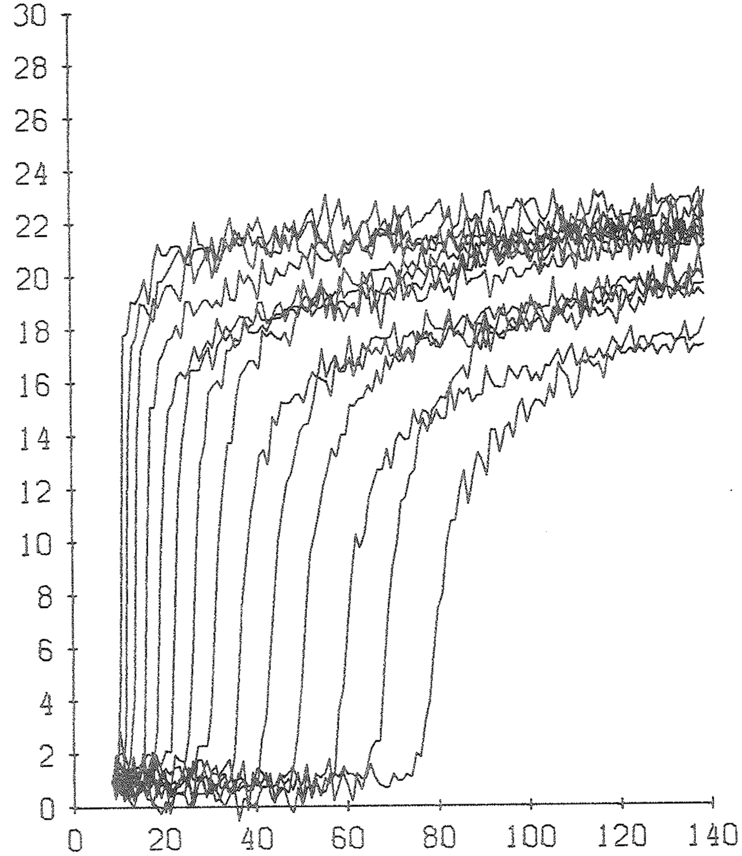

Fig. 5. Moisture distributions in sand-lime brick ($1950\ kg/m^3$) during free-water intake. Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

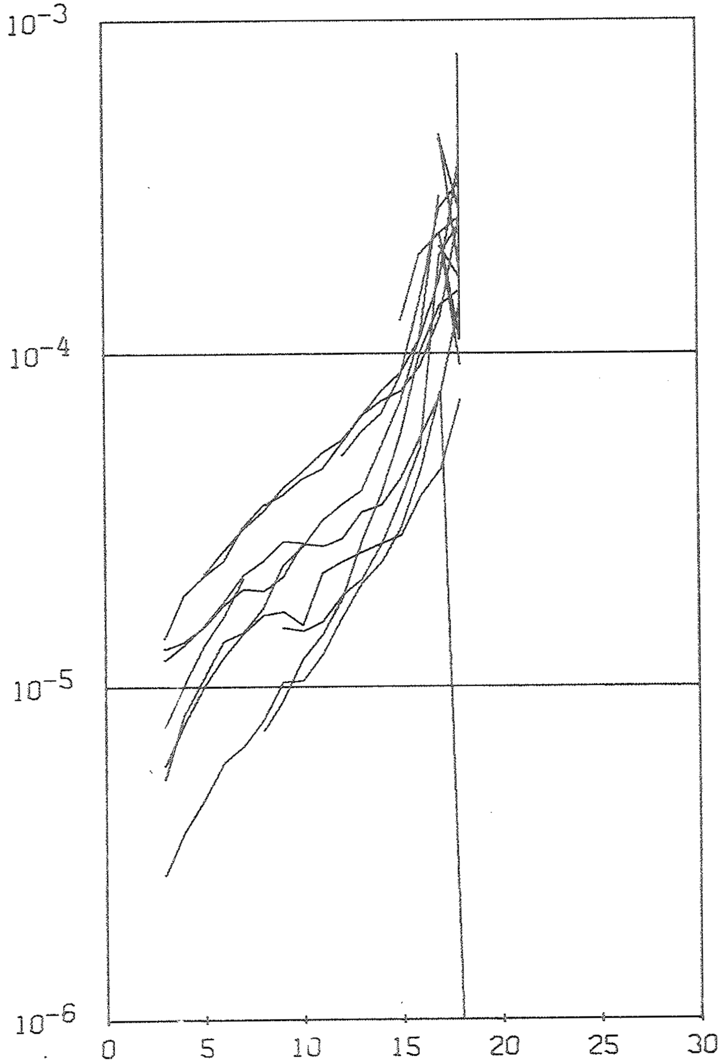

Fig. 6. Moisture diffusivity for sand-lime brick ($1950\ kg/\ m^3$) calculated from free-water intake. Height 3-6 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

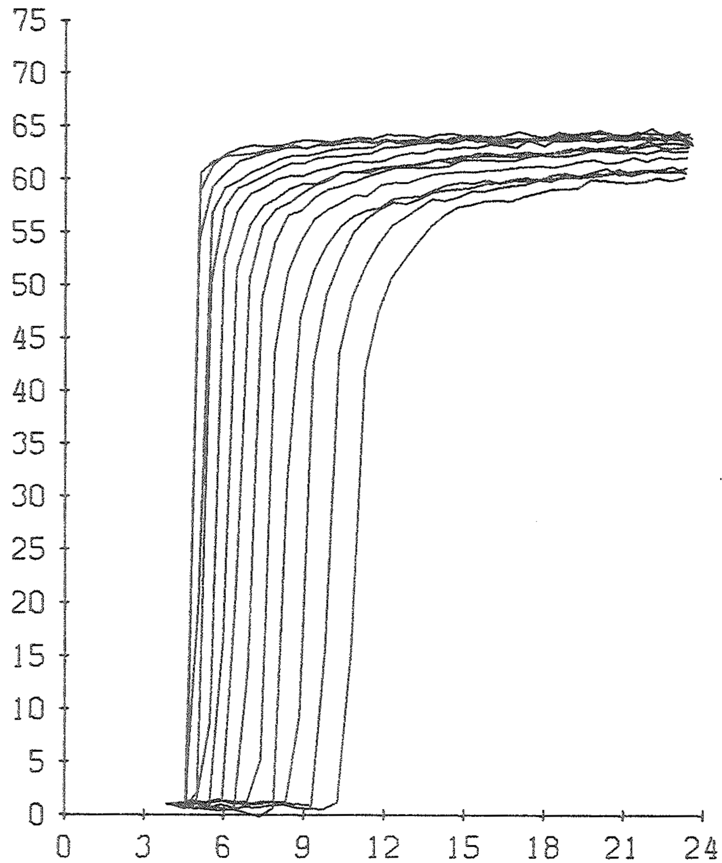

Fig. 7. Moisture distributions in moler brick ($790\ kg/\ m^3$) during free-water intake. Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

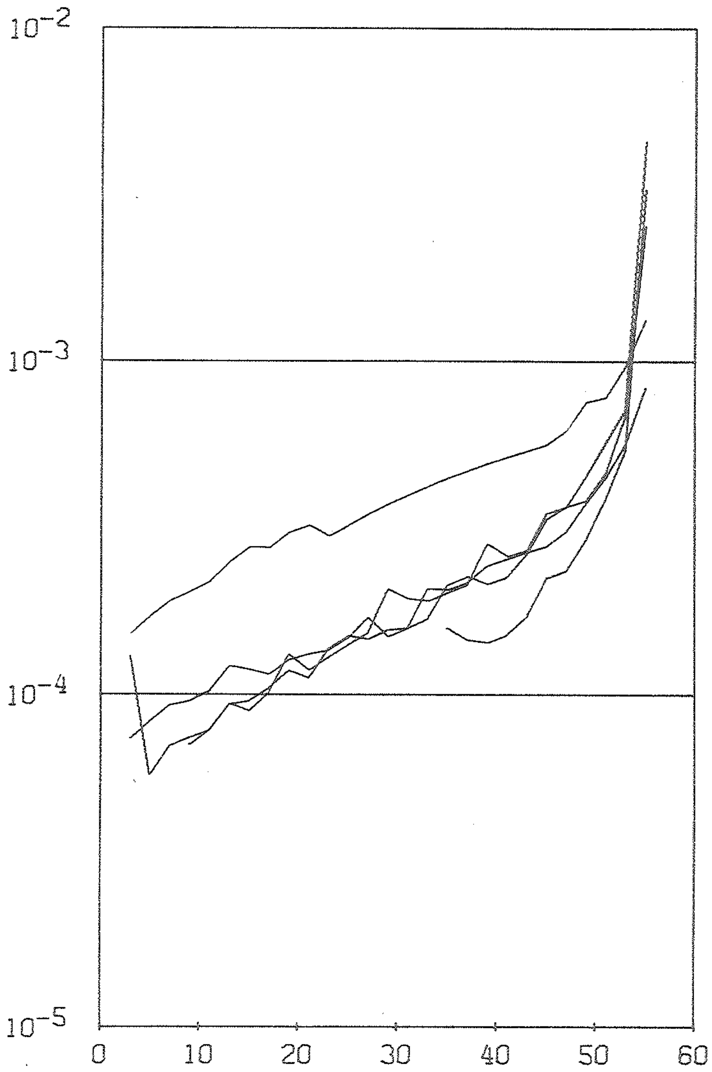

Fig. 8. Moisture diffusivity for moler brick (790 kg/m^3) calculated from free-water intake. Height 2-9 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

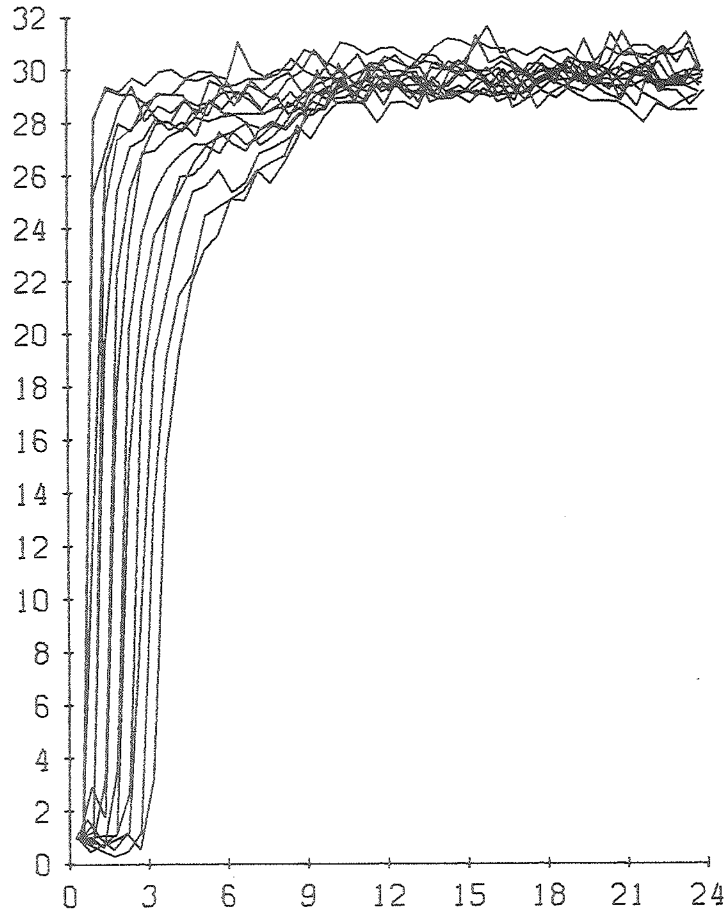

Fig. 9. Moisture distributions in brick A (1775 kg/m^3) during free-water intake. Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

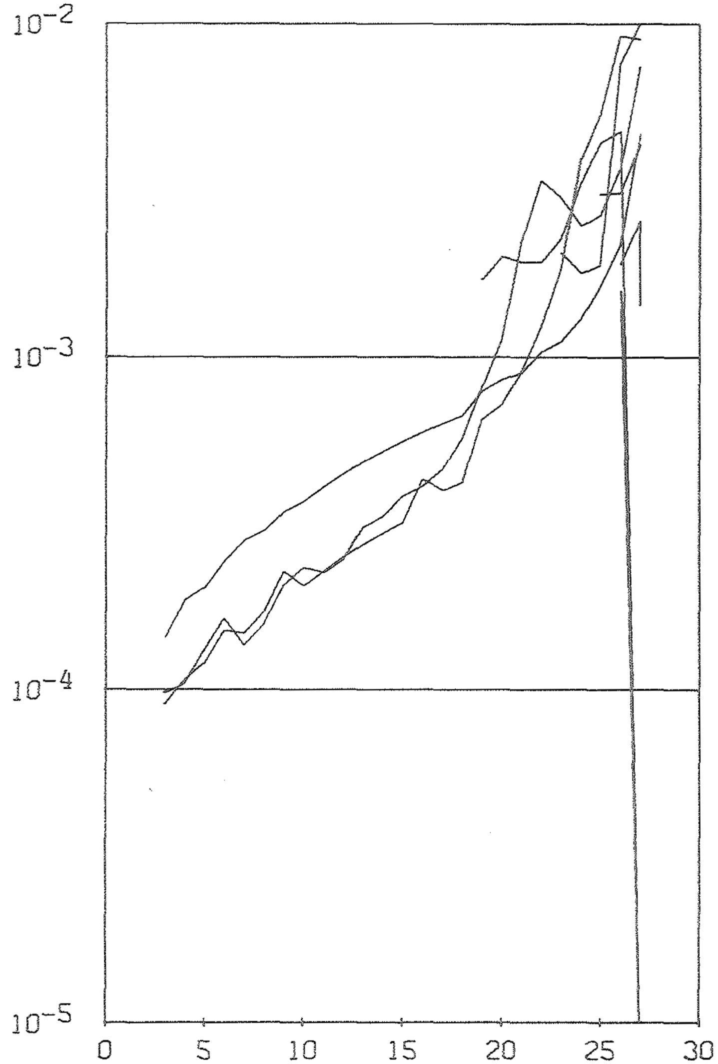

Fig. 10. Moisture diffusivity for brick A (1775 kg/m^3) calculated from free-water intake. Height 1-10 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

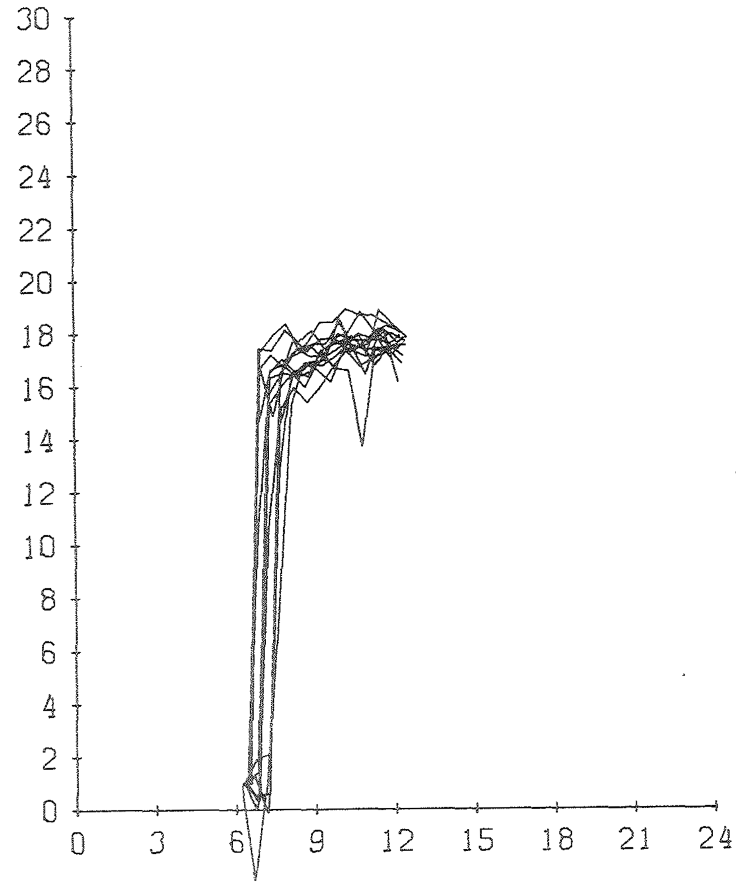

Fig. 11. Moisture distributions in brick B (2025 kg/m^3) during free-water intake. Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

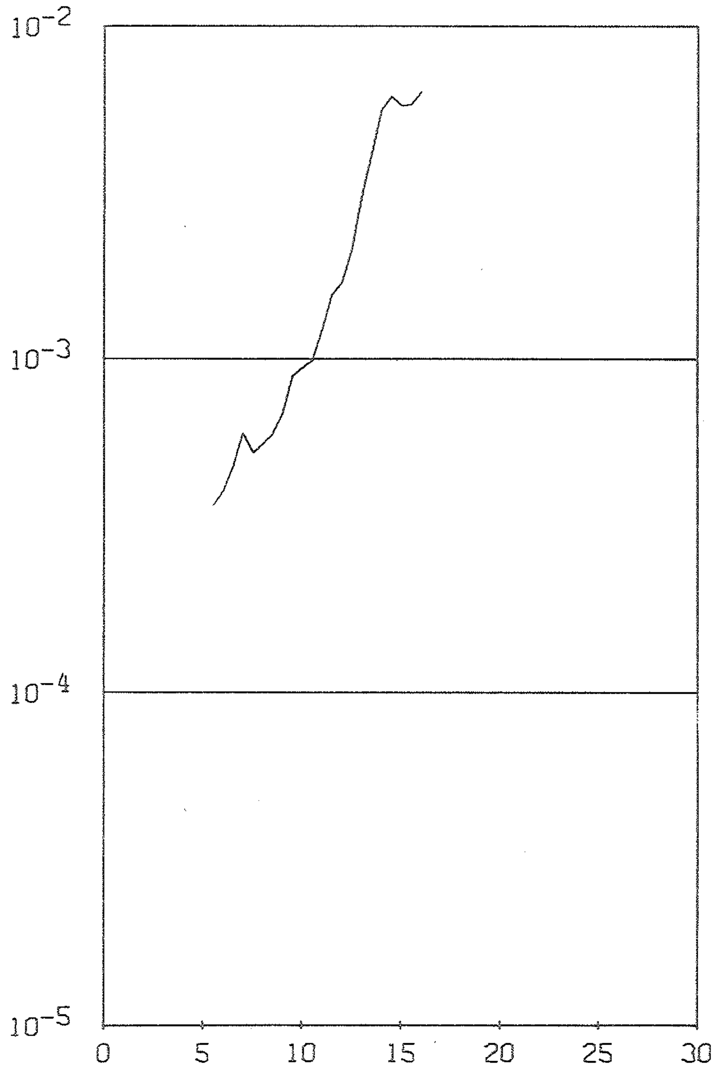

Fig. 12. Moisture diffusivity for brick B (2025 kg/ m^3) calculated from free-water intake. Height 1-7 cm. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).