Drying of cellular concrete measured with gamma ray attenuation

Nielsen, A. F.

Publication date:
1975

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Nielsen, A. F. (1975). *Drying of cellular concrete measured with gamma ray attenuation*. Technical University of Denmark, Department of Civil Engineering.

DRYING OF CELLULAR CONCRETE

MEASURED WITH GAMMA RAY ATTENUATION

A. F. NIELSEN

THERMAL INSULATION LABORATORY
TECHNICAL UNIVERSITY OF DENMARK

DECEMBER 1975

REPORT NO. 39

---

1. Introduction

Most building materials are made during processes, where water is used. Therefore the moisture content will be high in the beginning. The equilibrium moisture content found from the sorption isotherm is much lower. This surplus of water is removed by drying. Because of this, drying is a process of great importance.

This article describes the drying of cellular concrete and calculation of the moisture diffusivity from the measured moisture distributions. Measurements on cellular concrete have earlier been made by Krischer [3] and Kooi [2]. Their measurement of moisture content was made by electrical capacitance and resistance. We have measured moisture content by gamma-rays.

In the evaluation and drawing of results a computer has been used.

2. Theory

The drying-rate is found to be dependent on the outside conditions: Temperature, relative humidity, and air velocity. Krischer [3] has made a theory, where the drying could be divided in 3 regions. These regions are very important as a help to understand the drying process. The transfer of moisture could be as diffusion or liquid flow. The first region is of liquid flow. The third region consists of diffusion flow. The second region is a mix of both types of flow.

It is normally assumed that the moisture flow could be handled as heat flow, as a potential flow. The equation of moisture flow is:

$$q_m = - D \rho \text{ grad } \psi$$

where q_m is the density of mass flow rate (kg/m^2s)
D is the moisture diffusivity (m^2/s)
ρ is the density of water (kg/m^3)
ψ is the moisture content (m^3/m^3)

This formula is assumed to guide the moisture flow, so that a transfer will occur as long as there is a potential difference. From a drying experiment it is possible to calculate the moisture diffusivity, if the moisture flow and the moisture gradient are known. If the drying is one dimensional and the bottom is tight, the flow through the top is easy to calculate when the moisture distribution is known at two hours. The calculation of the moisture diffusivity is done by the formula:

$$D(\psi) = \frac{1}{\left(\frac{\partial \psi}{\partial z}\right)_z} \int_0^z \frac{\partial \psi}{\partial t} \, \partial z$$

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

As to this material, it is found that the moisture diffusivity is dependent on the moisture content. That complicates the calculation of the moisture diffusivity, the reason why we have chosen to use a digital computer for the calculations.

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 [4] with a 100 mCi Am-241 source with 60 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 10 mm in width. Fig. 1 shows the equipment.

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:

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

where ψ is the moisture content (m^3/m^3)
μ is the absorption coefficient for water (m^2/kg) (0.1907)
ρ is the density for water (kg/m^3) (~ 1)
x is the concrete thickness (m) (~ 12.15)
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 ± 0.2%vol, and for 60%vol ± 0.5%vol.

4. Experiment

The first experiment is made on a vacuum saturated specimen (no. 197) with a starting moisture content of 78%vol. The drying conditions are air temperature 23°C, dew point 12°C, and air velocity of 1.5 m/sec. The specimen was cylindrical with diameter 12 cm and height 5 cm. All surfaces were tightened except the top. The research material came from Gasbeton, the Danish factory. The measurements of the moisture distributions by gamma-ray equipment were manually made with time intervals of 8 - 16 hours. In fig. 2 the measured moisture contents are shown as symbols (one for each time level). The time values are experimental hours. Also the best fit for the moisture distribution at each time level can be seen in this figure. This polynomial regression has been made by means of a computer. The curves consist of 2 parables with a joint point, where the slope is the same. It is seen that in most cases the fit is rather good, if the standard deviation of the gamma-ray measurements is taken in account. The use of mathematical expressions for the moisture distributions gives advantages for the later calculation of the moisture diffusivity.

On the basis of fig. 2 and 3 it is possible to divide the drying process into 3 parts. First the drying from saturation (78%vol) to a point (35%vol), where the moisture content is the same all over the specimen. For this part of the drying it is mostly liquid transfer guided by the surface moisture content.

The second part of the drying is in an area, where the moisture content is approx. the same all over the specimen. This takes place from 35%vol to 25%vol. It has been found at all our experiments, and the explanation of it must be found in the structure of the cellular concrete, and possibly also in the specimen size. In this case the thickness is of 5 cm. The third part of the drying is the continuation from the 25%vol to the equilibrium moisture content at about 3%vol. In this part the drying rate is falling as the diffusion process is going to be more and more important.

5. Water diffusivity

The water diffusivity was first calculated from the measured moisture distributions, as shown in fig. 2. This was done by use of the formula [2]. The parable approximation is used, as it gives the moisture content at all the points in the specimen.

From this approximation it is possible to calculate the moisture content gradient and the moisture flow, and from that the water diffusivity. This calculation was made by a computer, and the resulting water diffusivities were drawn by a plotter. Fig. 4 shows the result. Each curve on the plot represents a calculation from 2 succeeding moisture distributions, for instance the experimental times of 661o.6 and 6618.6. The water diffusivity curves on fig. 4 could be divided in 2 regions, first the part from 5%vol to 25%vol, and second the rest. The first part gives a water diffusivity with a minimum value at about 9%vol. From 1o%vol to 22%vol the water diffusivity is rising. The second part shows a rather wide spread, which may be due to the long time intervals between the measurements, and possibly also due to the non-homogeneity in the specimens.

It should be possible therefore to get better results if the moisture distributions were known at short intervals of time. In the present case it has been done by theoretical calculation of new moisture distributions between the measured ones. For the high moisture contents new curves have been calculated by use of best fits of parables. These new curves are found to have the same form as the ones measured. From these curves with time intervals of 1.5 hour a new calculation of the water diffusivity is made. Fig. 5 shows a better result. The water diffusivity is found to have a minimum value at about 6o%vol. A comparison between fig. 4 and fig. 5 shows that the diffusivity has a maximum at about 3o%vol, but the value of the diffusivity is undefined. This is caused by the fact that the moisture content for this part of the drying is constant.

6. Later experiments

The first experiments were made with manual measurements, but later it has been possible to make automatic measurements. This was done by measuring the moisture distribution every half hour, and the result was punched on papertape. Fig. 6 and 7 give the measured moisture contents in dependence on the time. Each curve gives the moisture content for a single measured point in the specimen. The moisture distributions are of the same type as found in the first experiment with 3 parts. This is rather interesting, as the part of constant moisture content is found also if the time intervals between the measurements are short. This area of constant content has been found at all our drying experiments and must be explained through the structure of the cellular concrete. The small fluctuations of the curves are caused by the statistical nature of the gamma-ray emission. The later part of the curves (fig. 7) have approximate parabolic forms. In the first part (fig. 6) there is an interesting detail. The moisture content in some of the heights shows a sudden drop of about 2%vol in 1 hour. This change could not be found by the manual measurement method. Such changes have been found at all the experiments and could not be random variations. The most probable explanation is that at a certain moment a great pore has suddenly been emptied. Then the drying is continuing normally again. This is also in accordance with the theories of hysteresis.

From these moisture distributions the water diffusivity is calculated as earlier mentioned. The moisture diffusivity (fig. 8) gives the same picture as found before. Again it is impossible to get values about 30%vol. For the moisture contents exceeding 35%vol there is a rather wide spread of more than one decade. It is possible that a better vacuum saturation could give a more uniform moisture content at the beginning and therefore avoid hysteresis. But the sudden drops in moisture content could be destroying every chance of getting more accurate results for moisture contents over 35%vol. For values of the moisture content lower than 25%vol the water diffusivity is rather well defined. This is very important, as most practical constructions have a moisture content in this part.

7. Conclusion

These results of the drying experiments could be compared with the earlier experiments by Kooi [2] and Krischer [3] (fig. 9). On fig. 9 is also indicated the result from Cammerer [1], who has made experiments with capillary rising. There the same curve form for moisture contents between 8%vol and 25%vol is found. In the area where the diffusivity is rising with rising moisture content, all the types of cellular are alike. For the part from 25%vol to 35%vol our experiments have found an area, where the moisture content is nearly constant. This has not earlier been found, but it is in accordance with the pore size distribution. If the number of pores is small, the moisture diffusivity should be high, and that is what is found. For the last part from 35%vol to 70%vol the moisture diffusivity is not very well defined, but it is found that the moisture diffusivity has a minimum value when the moisture content is about 60%vol. This has also been found by Kooi. There is some evidence that Krischer's moisture distributions could also give a moisture diffusivity curve of this type.

The results of our experiments are much dependent on the measuring method. There is no doubt that this method could give much better results for such drying experiments. Also it has been a great help to use a digital computer for calculating the moisture diffusivity and making drawings of the results on a plotter. A more comprehensive describtion of this and other experiments on cellular concrete is found in [5].

This research has been granted by the STVF, The State Research Council for Technical Science in Denmark.

8. References

[1] Cammerer, W.F.: The Capillary Motion of Moisture in Building Materials. 2 Rilem/CIB Symposium, Rotterdam 1974.

[2] van der Kooi, J.: Moisture Transport in Cellular Concrete Roofs, 1971.

[3] Krischer, O.: Die wissenschaftlichen Grundlagen der Trocknungstechnik. Springer Verlag 1963.

[4] 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.

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

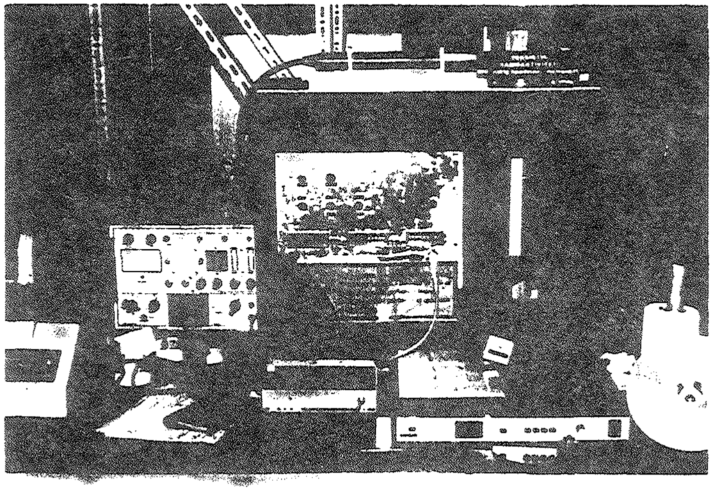

Fig. 1. Gamma ray equipment with electronics for automatic measurements.

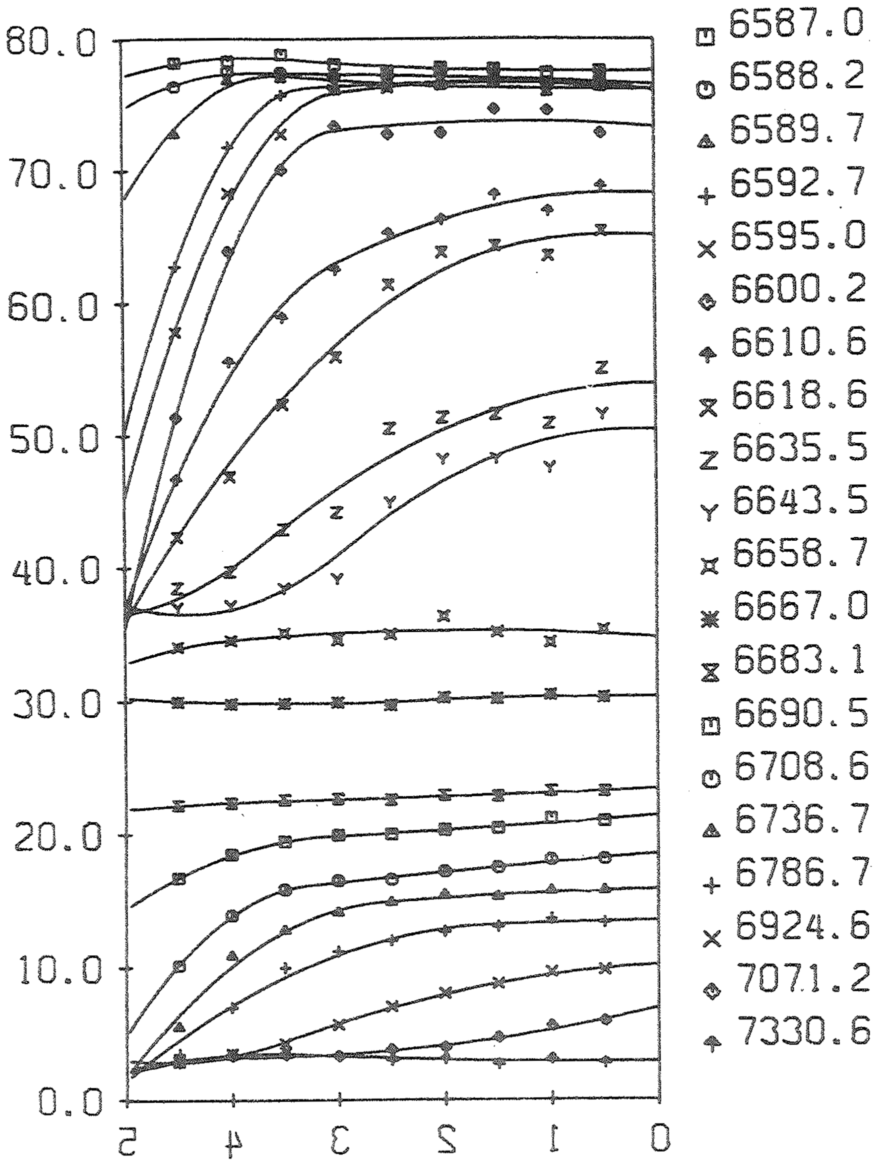

Fig. 2. Moisture distribution in specimen no. 197 during drying experiment. Moisture content (% vol) versus distance (cm) from the closed side. To the right the symbols of the measured values at the experiment time (hours).

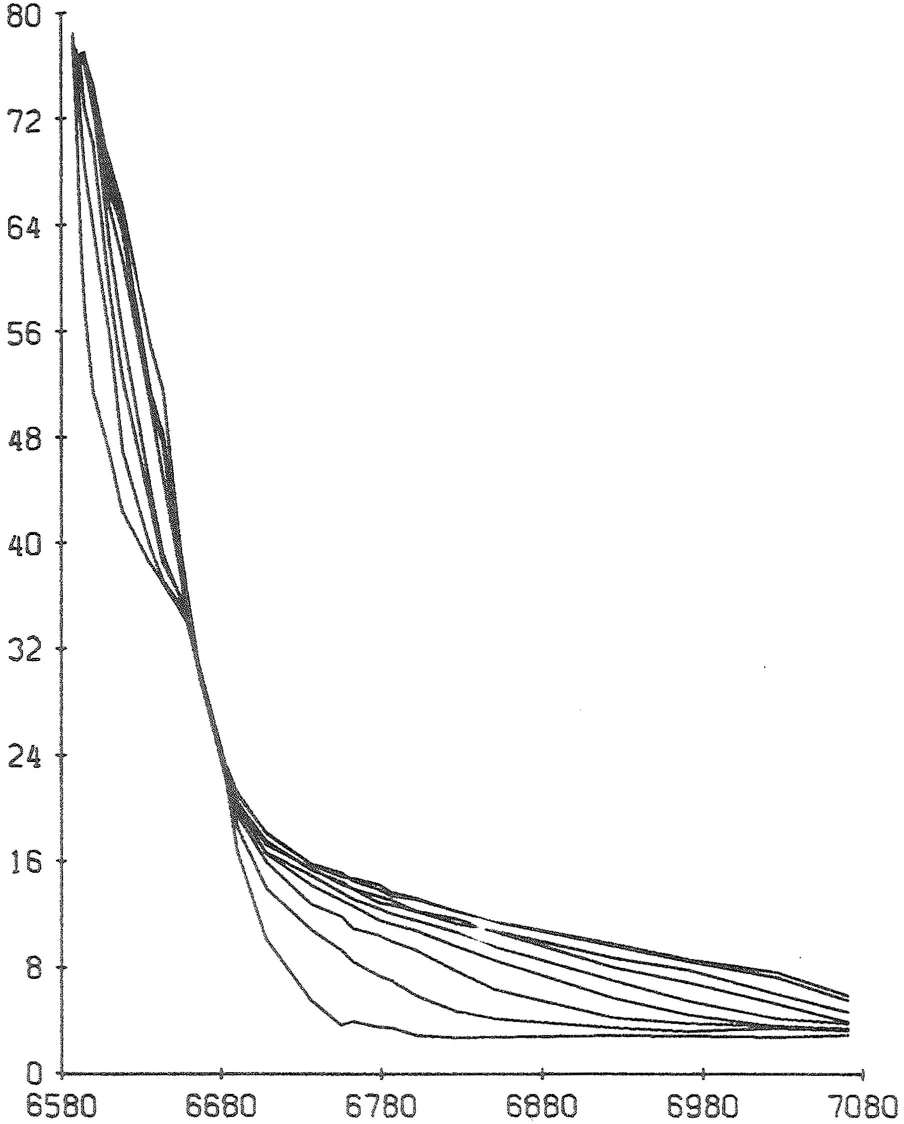

Fig. 3. Moisture distributions in specimen no. 197 during drying experiment. Moisture content (% vol) versus experimental time (hours). The curves have been plotted between values measured in the same height in the specimen.

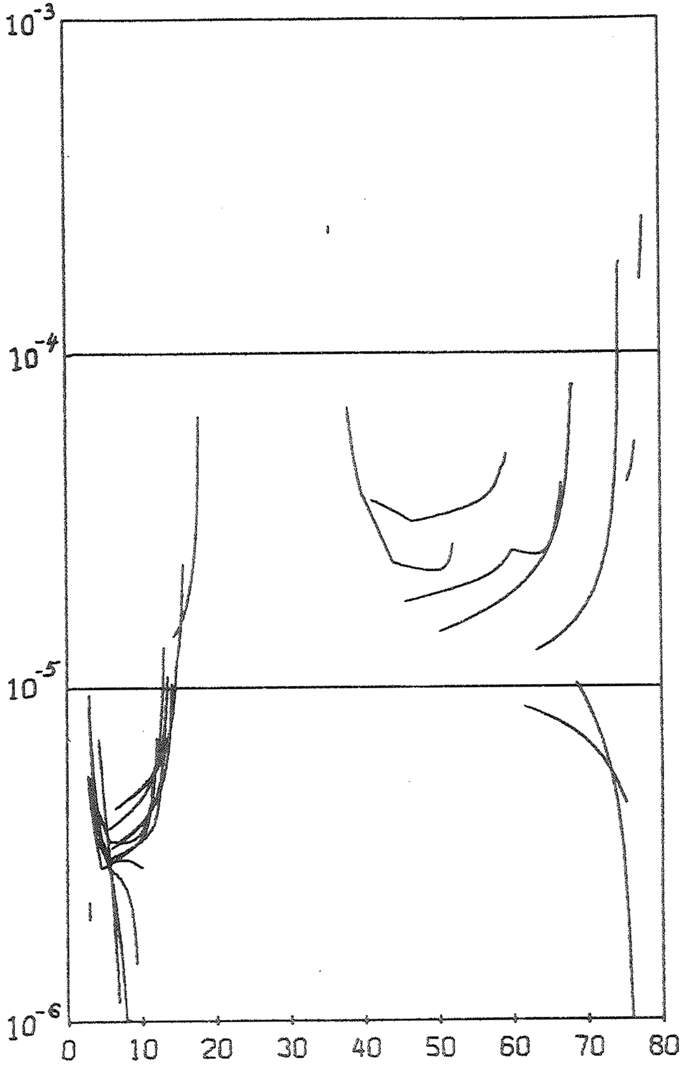

Fig. 4. Moisture diffusivity calculated from drying experiment (fig. 2). Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

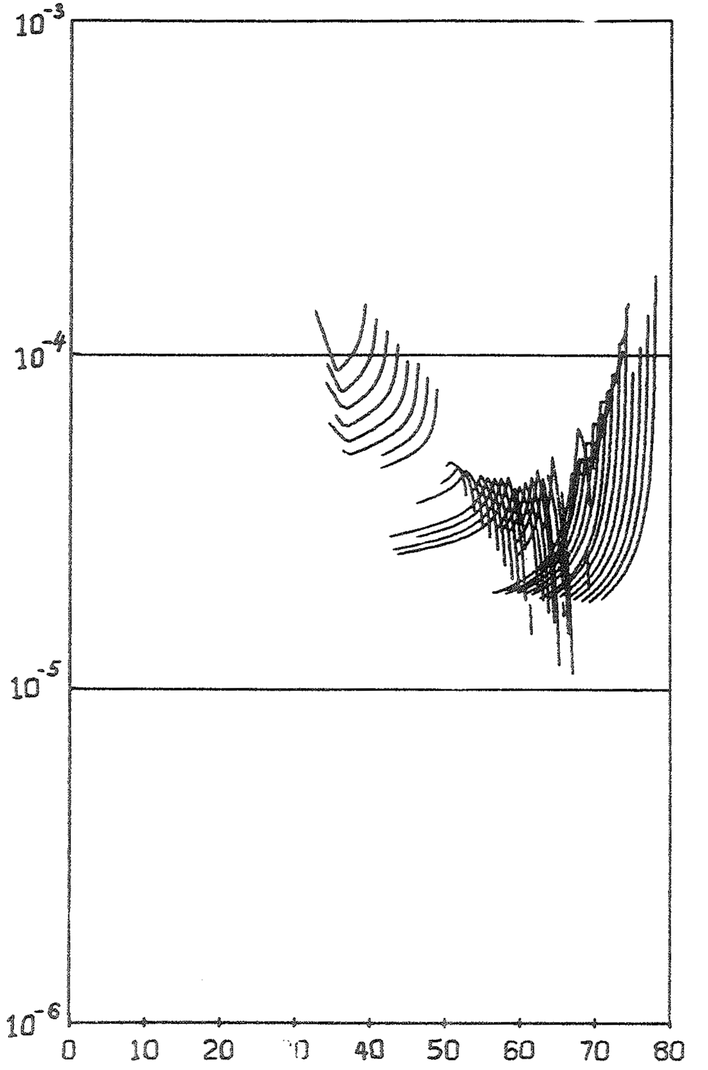

Fig. 5. Moisture diffusivity calculated from drying experiment with correction of moisture curves. Diffusivity (m^2/h) (log-scale) versus moisture content (% vol).

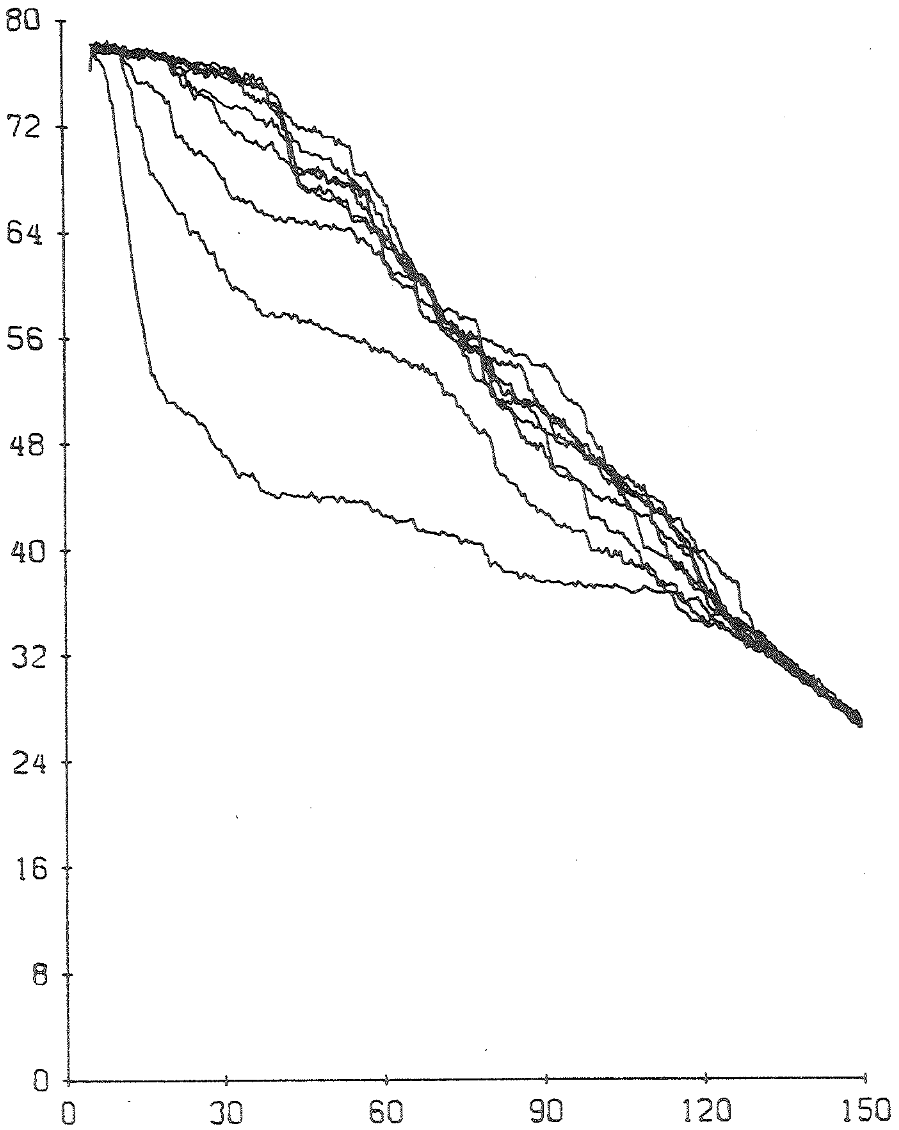

Fig. 6. Moisture distributions in specimen no. 196 during drying experiment (measurement every ½ hour). Moisture content (% vol) versus time (hours). The curves have been plotted between values measured at the same height in the specimen.

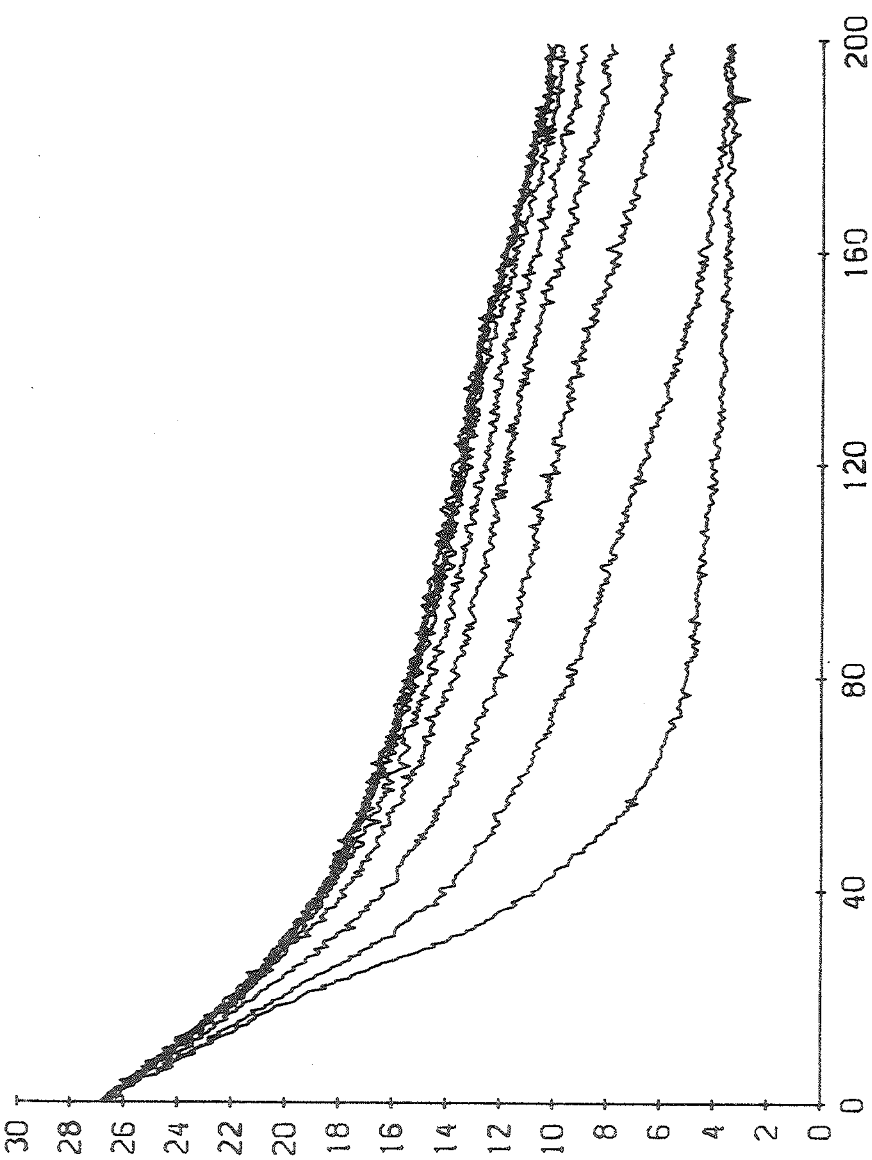

Fig. 7. Moisture distributions for the same experiment as in fig. 6, but at a later time. Moisture content (% vol) versus time (hours). The curves have been plotted between values at the same height in the specimen.

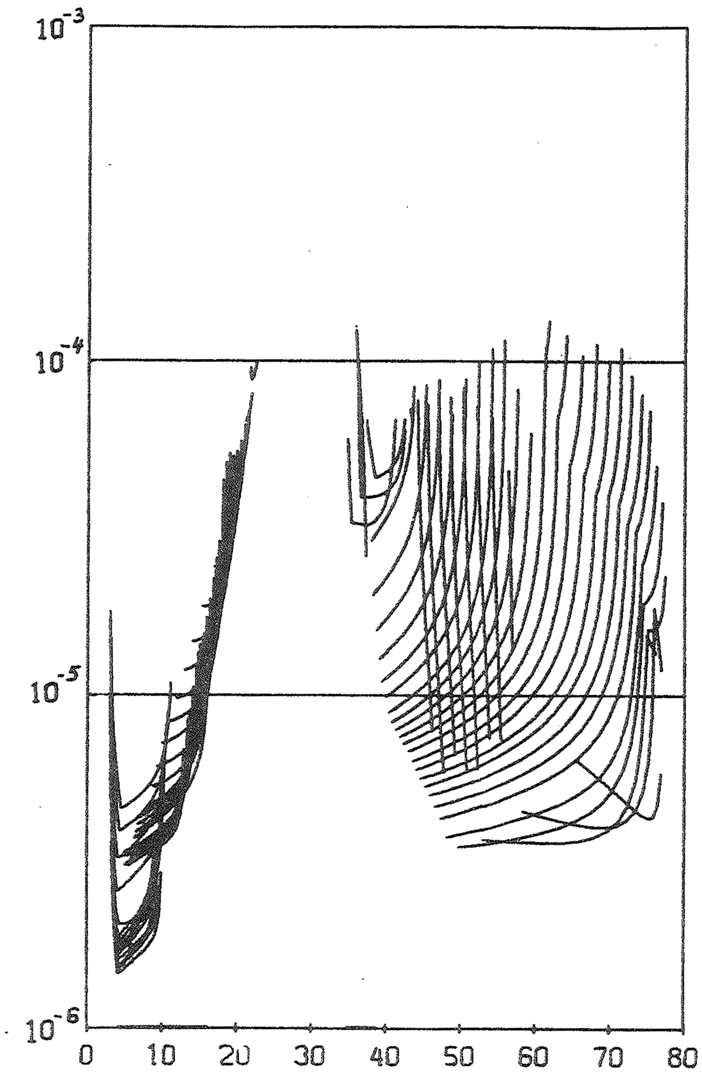

Fig. 8. Moisture diffusivity calculated from the drying experiment (fig. 6 and 7). Diffusivity (m^2/h) (log scale) versus moisture content (% vol).

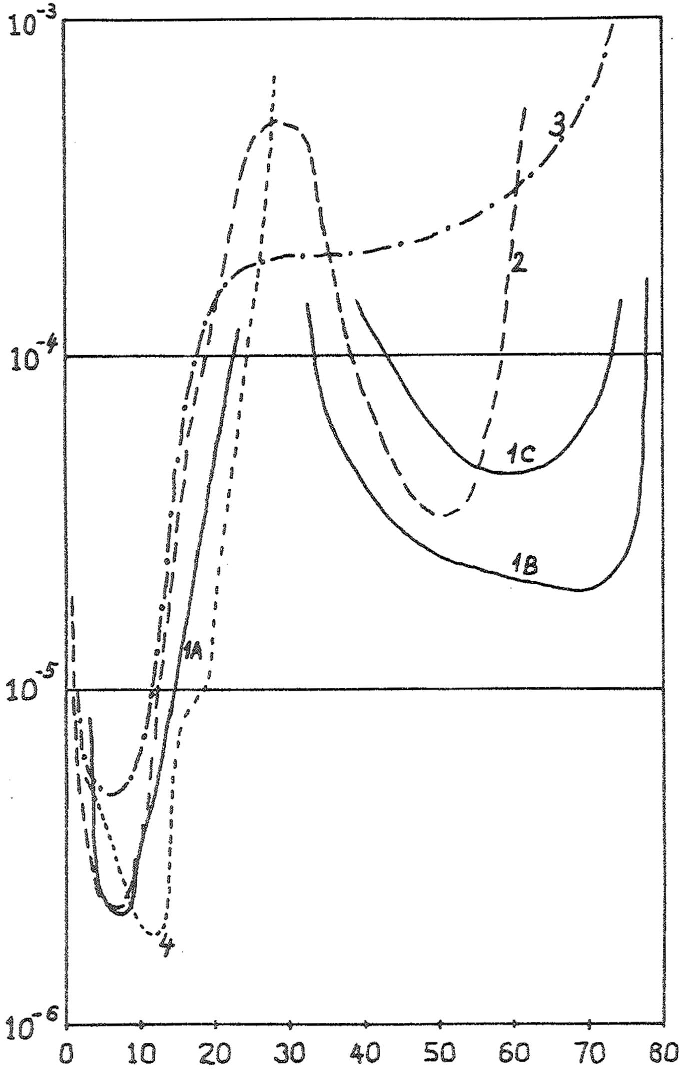

Fig. 9. Moisture diffusivity for cellular concrete calculated by

1A Nielsen
1B Nielsen (lower limits)
1C Nielsen (upper limits)
2 van der Kooi
3 Krischer
4 Cammerer