MEASUREMENTS OF DRYING-OUT ON CELLULAR CONCRETE

Moisture distributions measured by gamma-ray-attenuation method and moisture diffusivity calculated by computer

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MEDDELELSE NR 26

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Many drying-out experiments have been made in the course of time because this process is of great importance in the building material science. In most of the materials only the mean moisture content has been determinated at different times (by weighing). KRISCHER [1] has made a theory of drying on the assumption that the only potential is the moisture gradient. Krischer has also shown that the drying-rate is important as a factor to divide the drying in 3 regions. The critical moisture content is dividing point between the liquid and the vapour phase.

To get more knowledge of the drying process it is necessary to know the moisture distributions during the experiment. This has been done by KRISCHER [1, 2], who has measured the moisture content by electrical capacity at 10 Mhz (see fig. 1). VAN DER KOOI [4] has used electric resistance measurements for his determination of the moisture distribution (see fig. 3). These measurement methods are both of them difficult to use because the calibration is complicated - and still it is possible for the same total amount of water to get different results if the water is distributed differently between the electrodes. Besides this the measurements are dependent of the temperatures.

From the moisture distributions it is possible to calculate the moisture diffusivity (D) from the equation:

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

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)

A more comprehensive description is found in both Krischer and van der Kooi. The moisture diffusivity curves are found in fig. 2 and fig. 4.

Results of own experiment

You will only find a short description of one selected experiment, as a more comprehensive paper will appear in a year.

The drying-out experiment has been done on specimen no. 197, data:

dry density	568.9 kg/m^3
σ (dry density)	3.8 kg/m^3
height	50.3 mm
diameter	121.3 mm
max. moisture content	~ 78% vol (vacuum saturated)
air temperature	21,5 °C
relative humidity	52%
air velocity	~ 1,5 m/sec

The measurements of moisture distributions have been done by the gamma-ray-attenuation method as described in NIELSEN [3], and the results are shown in fig. 5. The measured moisture content values are used as computer input, and the moisture distribution curves are calculated by polynomial regression, and the polynomials are drawn by a plotter in connection with a computer.

The drying could be divided into 3 regions:

1. From 78% to 33% vol with liquid transport only.
2. From 33% to 23% vol, where the moisture content is equal all over the specimen. The evaporation and the moisture transfer must be in some kind of quasi-equilibrium.

3. From 23% vol to equilibrium. Moisture transfer by diffusion and capillary diffusivity.

In fig. 6 the same experiment is illustrated in another way. Between the measured points there are drawn lines - one for each of the 9 heights in the specimen. Again the same 3 regions appear. In the last region the drying curves for the layers are almost parabolic.

How to define the critical moisture content?

From the moisture distribution curves (the polynomials) it is possible to calculate the moisture diffusivity as a function of the moisture content. As the moisture content is a continuous function in the specimen both the density of moisture flow rate and the moisture gradient will be continuous. Furthermore, the moisture diffusivity as a function of the moisture content will also be continuous and easily calculated by a computer and plotted. If the calculation is made from the curves in fig. 5 the result is very confusing - and useless - because the mean values of the moisture content and of the moisture diffusivity are calculated in large time intervals. Therefore it is necessary to have moisture distributions in rather small time intervals.

From the measured values we have used polynomial regression to calculate new theoritic moisture distribution with time intervals of 1.5 hours. This has been done for region 1 from (experiment time) 6586 h. to 6654 hours.

Based on these curves with 1.5 hours intervals the moisture diffusivity is calculated, see fig. 7. The vertical lines in the figure come from the calculation at the closed side, where $q_m = 0$ and the moisture diffusivity consequently infinity. The rest of the curves define an area for the moisture diffusivity. There is one maximum at 75%, another at 35% and a minimum at about 60%. The size of the area is an expression of both the statistical variations and the pore size variations. To show the variation of the moisture diffusivity through the speciman calculations for different layers have been made. On fig. 8 the layer 15-25 mm from the closed side. It is seen that the curve form is the same as found for the whole specimen, but the moisture diffusivity is much better defined. The variations of the moisture diffusivity from layer to layer in the specimen could be caused by inhomogeneity in the pore structure, and possibly the moisture diffusivity is also a function of the moisture gradient. But this would require a comprehensive analysis.

Correlation with earlier experiments

If we compare the moisture distributions (fig. 1, 3, 5) it is easy to see that our results and van der Kooi's are most alike. But neither Krischer nor van der Kooi have found a region, where the moisture content is equal all over the specimen. The differences may be caused by the dry density of the material and the drying-rate of the experiments.

If we compare the moisture diffusivity (fig. 2, 4, 7) we would see that according to Krischer the diffusivity is nearly constant between 30% and 60% vol, and van der Kooi's and own results show a minimum at about 60% vol.

If a mean diffusivity curve (from fig. 7) is used for a non-stationary calculation of the moisture transfer during drying-out of a specimen, we find moisture distributions alike the measured ones. This is taken as an expression that there is no risk in using the polynomial regression in the calculation of the moisture diffusivity.

Conclusion

The use of gamma-ray-attenuation could possibly give better results compared to other methods with less calibration work.

Computer calculations could give better utilization of the experimental results and of using statistical methods.

A region where the moisture content is equal all over the specimen has been found for all our experiments.

A minimum of the moisture diffusivity in the liquid transfer region has been found, for this material at about 60% vol.

REFERENCES:

[1] KRISCHER, O: Die wissenschaftlichen Grundlagen der Trocknungstechnik. Springer Verlag 1963.

[2] KRISCHER, O & K. MAHLER: Über die Bestimmung des Diffusionswiderstandes und der kapillaren Flüssigkeitsleitzahl aus stationären Vorgängen. VDI-Forschungsheft 473, 1959.

[3] 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.

[4] VAN DER KOOI: Moisture Transport in Cellular Concrete Roofs. Delft 1971.

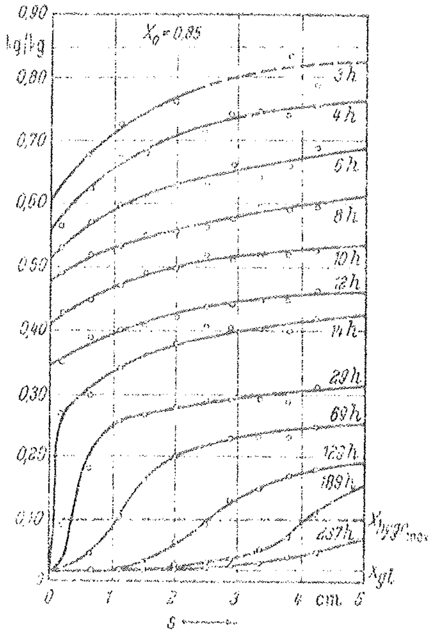

Fig. 1. Moisture distributions in a sample of cellular concrete during drying experiment. (Krischer)

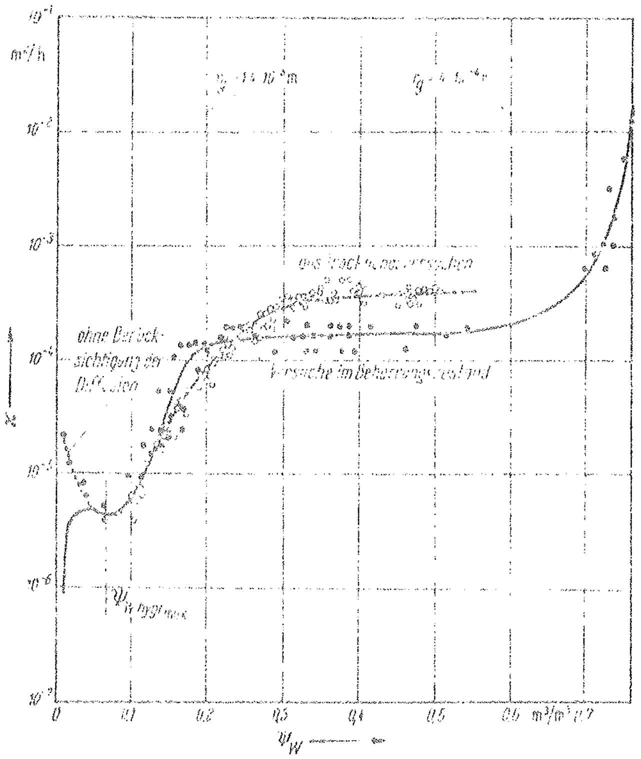

Abb. 164. Verlauf für Ytong (Γ_t = 650 kg/m³)

Zu den Abb. 163 und 164: Abhängigkeit der Feuchtigkeitsleitzahl κ vom Feuchtigkeitsgehalt ψ_W (bei 25 °C). Kreise: Meßwerte aus Trocknungsversuchen; Punkte: Meßwerte aus Versuchen im Beharrungszustand.

Fig. 2. Moisture diffusivity for cellular concrete by means of drying experiment (circles). (Krischer)

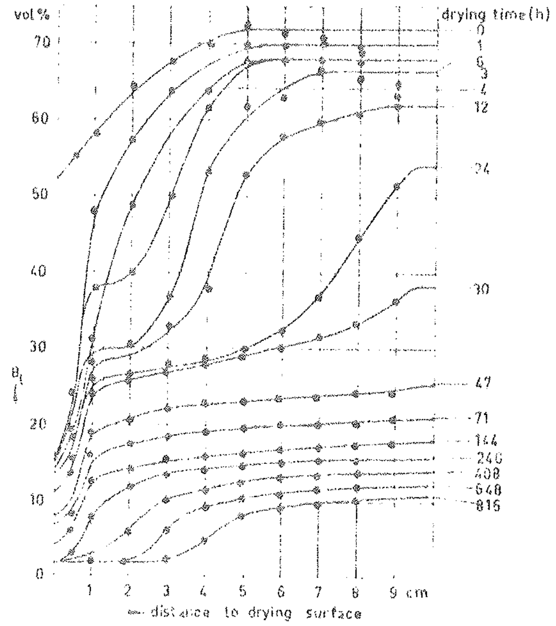

Fig. 3. Moisture distributions in a sample of cellular concrete during drying experiment. (van der Kooi).

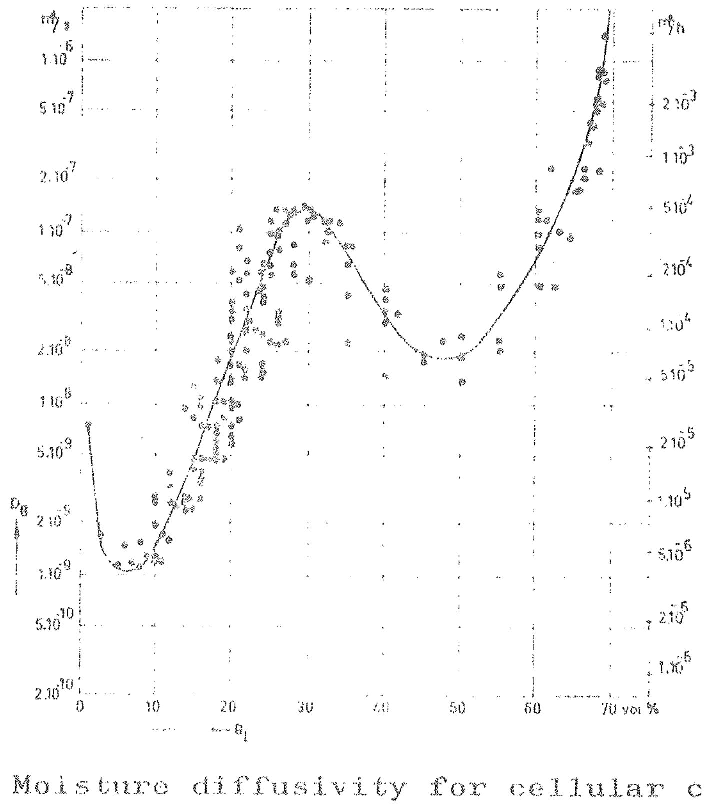

Fig. 4. Moisture diffusivity for cellular concrete by means of drying experiment. (van der Kooi)

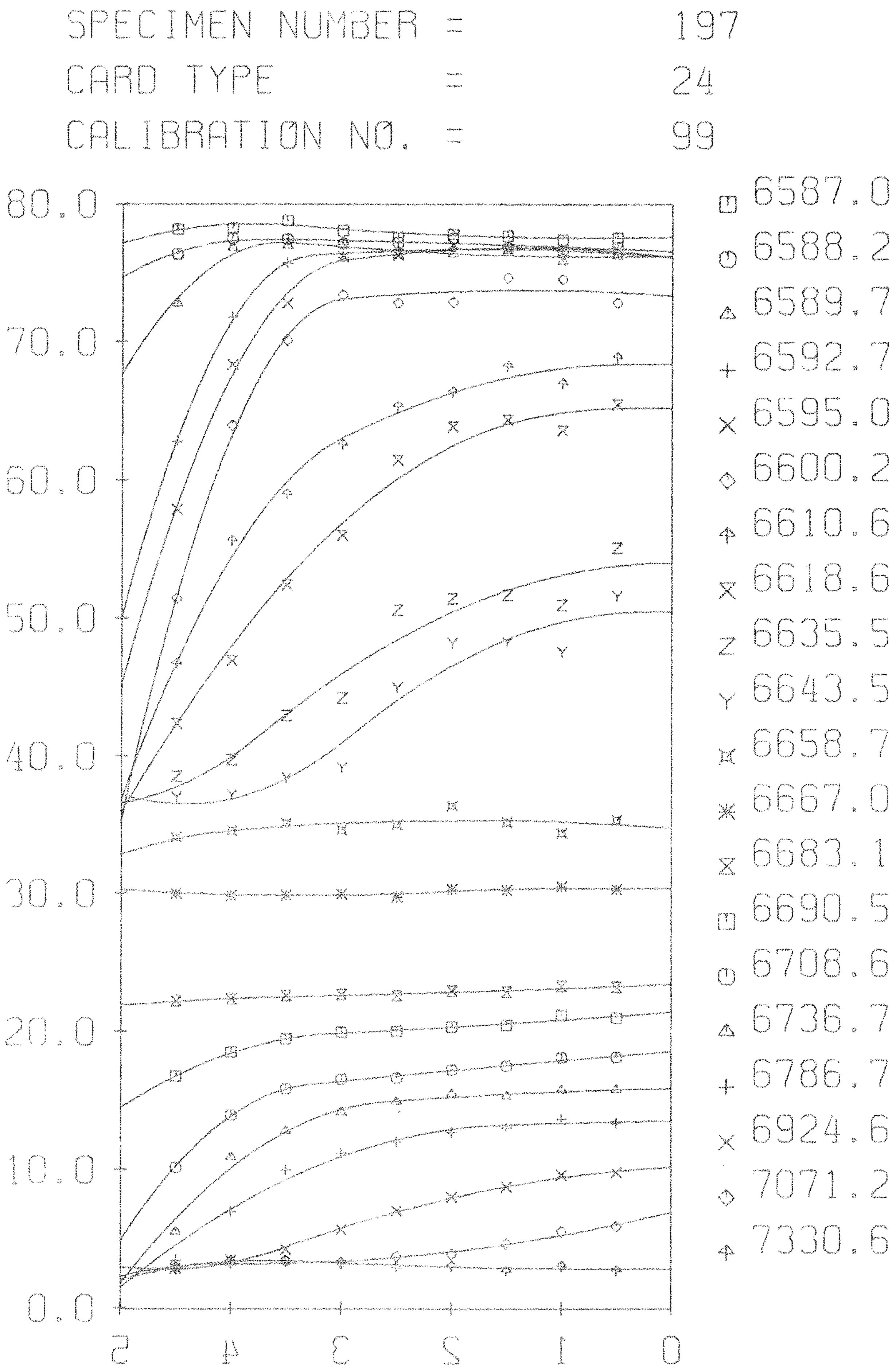

Fig. 5. Moisture distributions in sample 197 of cellular concrete during drying experiment. Moisture content (%vol) versus distance (cm) from the closed side. To the right the symbols of the measured values at the experimental time (hours). AFN 1973

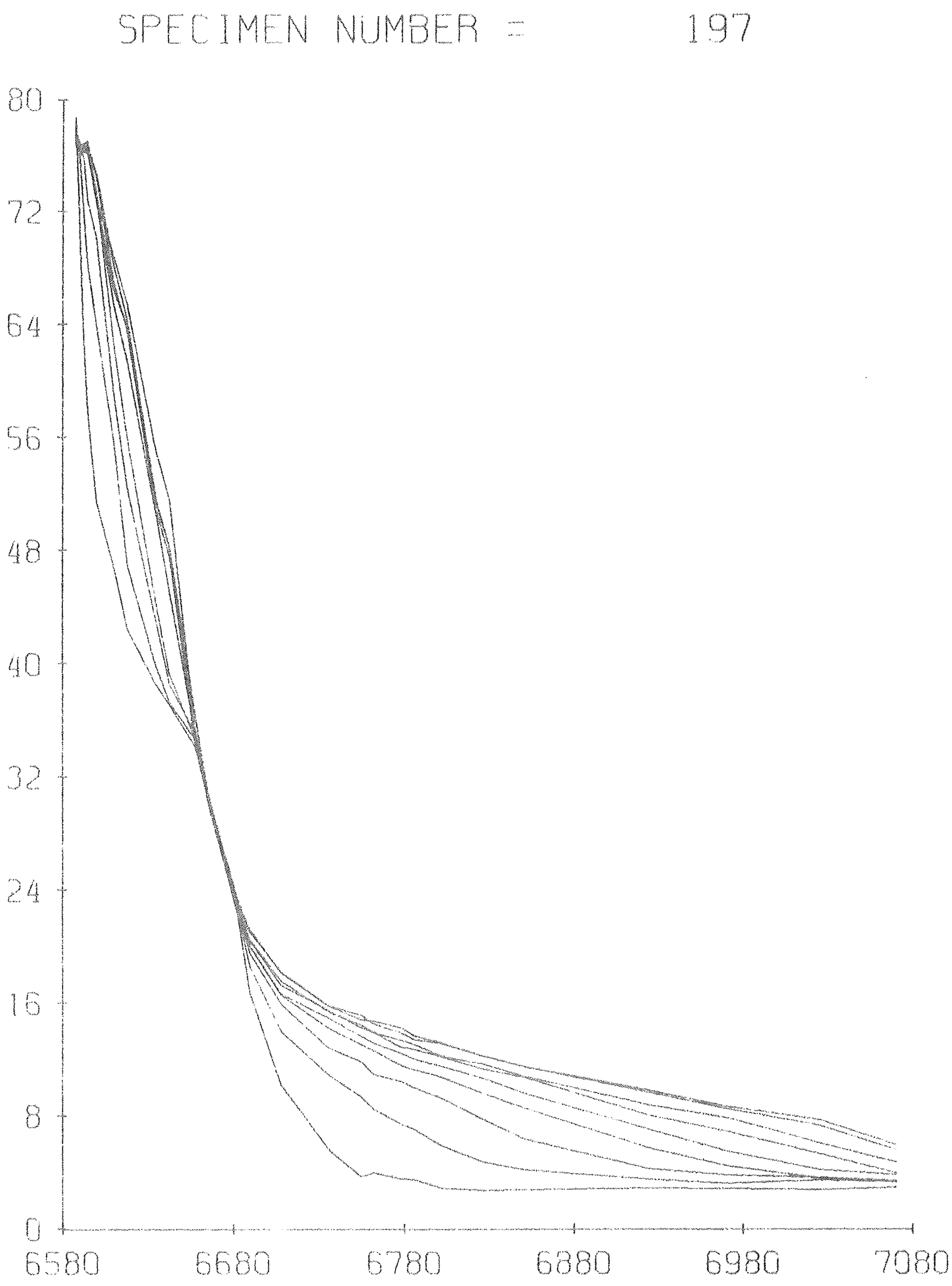

Fig. 6. Moisture distributions in sample 197 of cellular concrete during drying experiment. Moisture content (%vol) versus experimental time (hours). The curves have been plotted between values measured in the same height in the specimen. AFN 1973

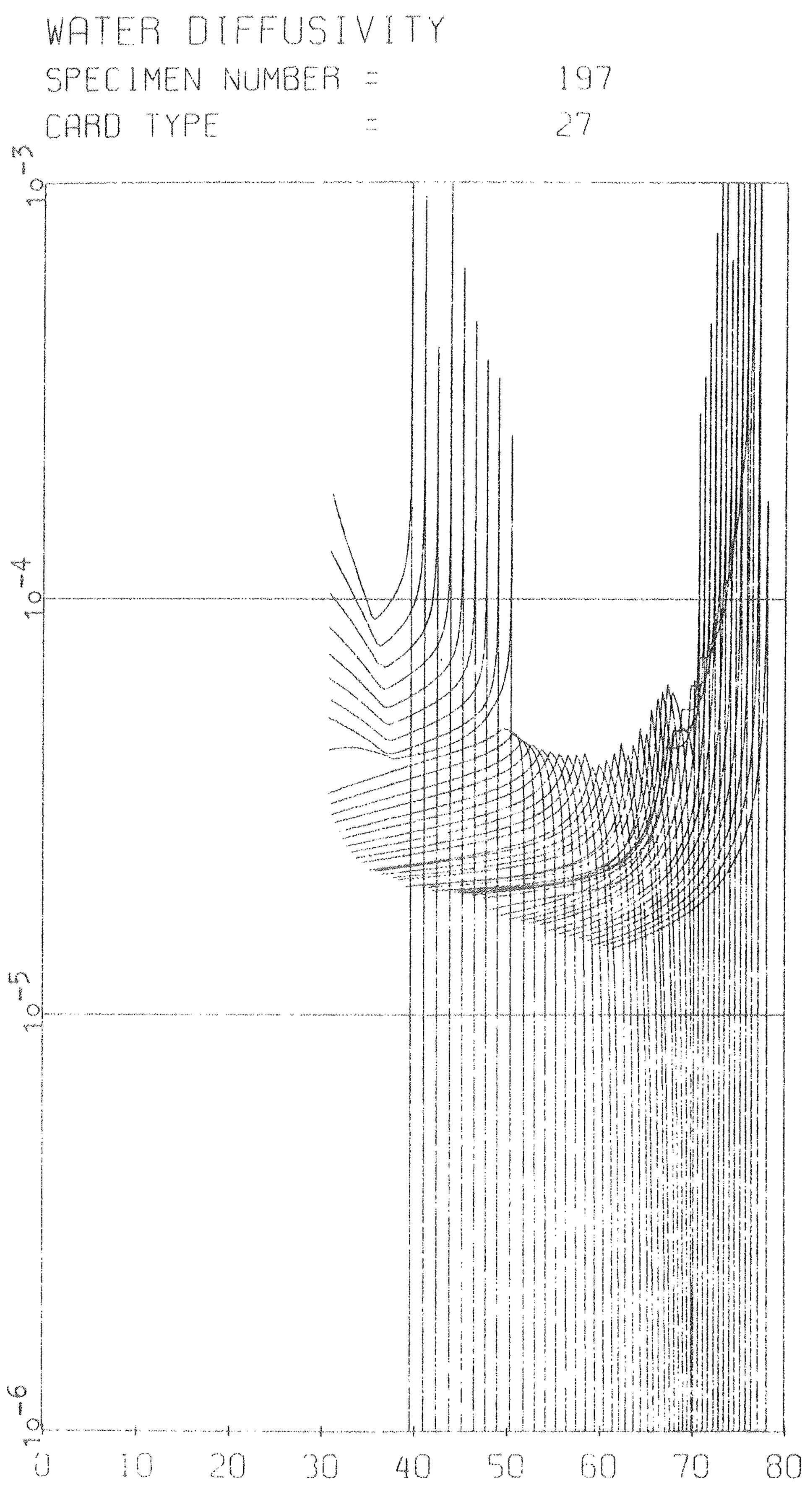

Fig. 7. Moisture diffusivity for cellular concrete by means of drying experiment (sample 197). Diffusivity (m^2/h) (log-scale) versus moisture content (%vol). AFN 1973

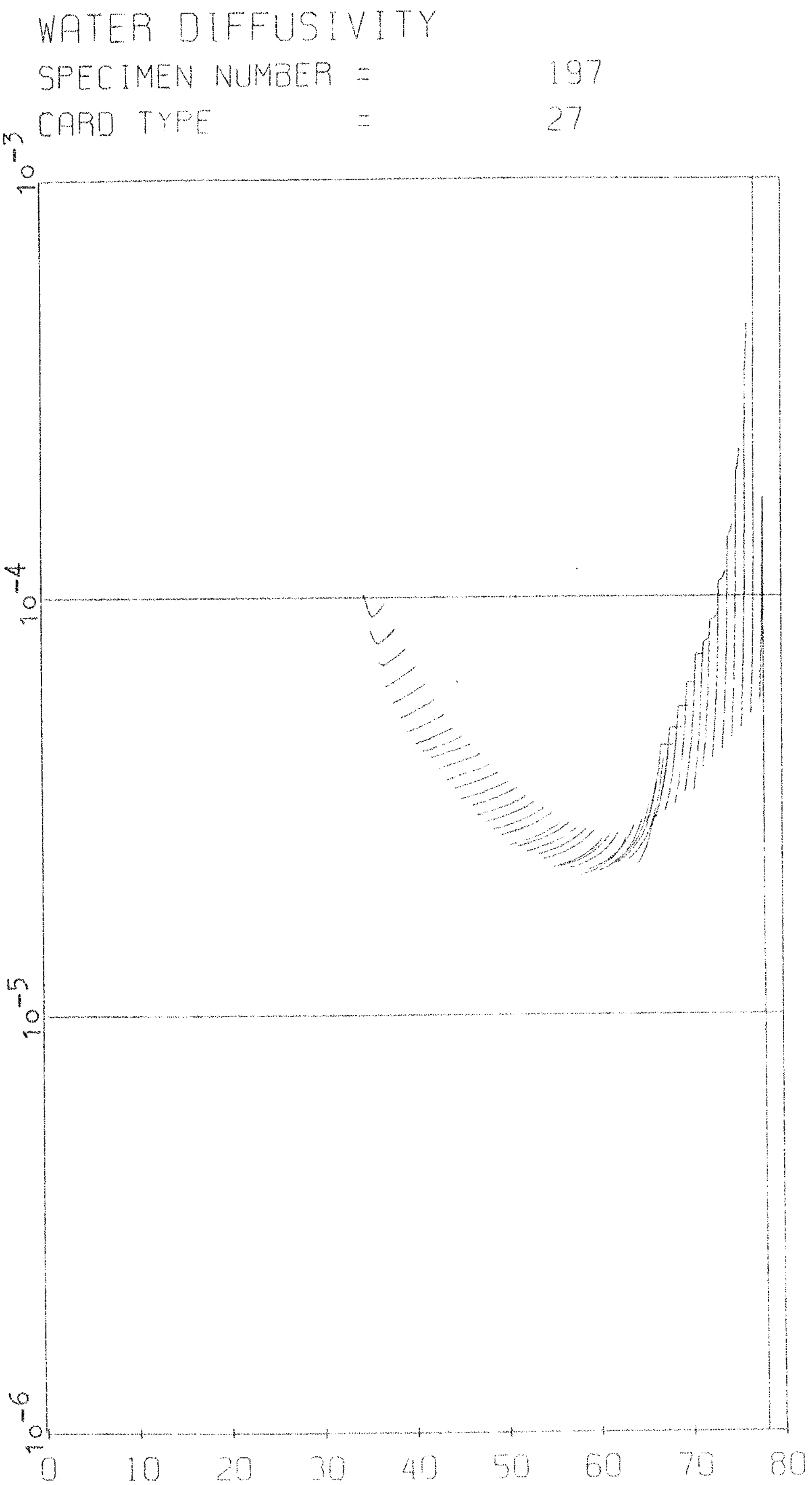

Fig. 8. Moisture diffusivity for cellular concrete by means of drying experiment (sample 197) for the layer between 15-25 mm from the closed side. Diffusivity (m^2/h) (log-scale) versus moisture content (%vol).

AFN 1973