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Hedenblad, Göran

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by

Göran Hedenblad

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SCIENCE PROJECT CT91-0737

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Background

The moisture permeability, or as it is also called the water vapour diffusivity (δ_v) for many modern building materials depends on the moisture content of, or the relative humidity (RH), in the material; see FIG 1.

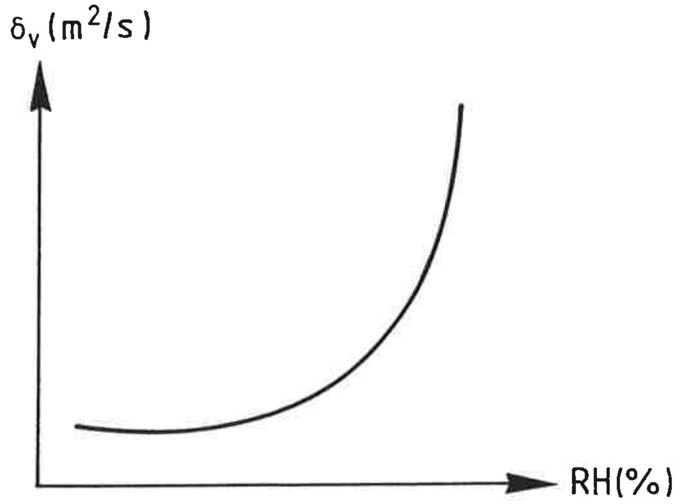


FIG 1. Moisture permeability (with the humidity by volume as potential) as a function of the relative humidity. In principle.

The moisture permeability of a given material also depends on the microstructure of that material. Materials with different microstructures probably do not have the same shape on the moisture permeability curve.

Theory

According to Fick's first law we can write

$$\vec{g} = - \delta_v * \text{grad } v \qquad (1)$$

$\vec{g}$ =	vector density of moisture flow rate	$(kg/(m^2,s))$
v =	humidity by volume in the pores of the specimen	(kg/m^3)

δ_v = moisture permeability with regard to humidity by volume (m^2/s)

For many materials, the moisture permeability is not constant, but varies with the moisture content in the material and with the temperature. δ_v may also be different if a material is under desorption or absorption.

δ_v in eq.(1) describes the total transport of moisture in the material. The moisture flow can theoretically be divided into two parts, one which depends on pure diffusion and one which depends on the capillary suction which acts on the moisture flow in the liquid phase.

Theory for the modified cup method

By using the cup method in a special way, it is possible to get δ_v as a function of the relative humidity. The modification was mentioned by Bazant and Najjar (1972) and has been developed for practical application by Nilsson (1980).

The following is almost directly from Nilsson (1980).
The moisture flow through a disc of a material is attained by placing a cup, with the disc as a lid and containing a saturated salt solution giving a humidity by volume v_1, in a climate room with the humidity by volume v_2; see FIG 2.

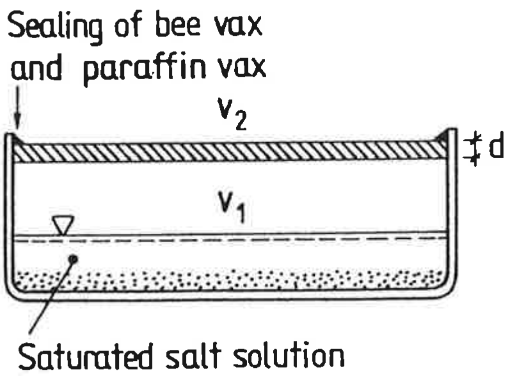


FIG 2 Principle of diffusion measurements with the cup method.

The moisture flow through the material is determined by weighing until stationary flow is obtained. The average moisture permeability in the interval between the two climates is obtained by one measurement. More information can, however be obtained by using a series of measurements.

The moisture flow through the disc in FIG 2 is described by eq.(1), and in one dimension we have

$$g = -\delta_v * dv/dx \quad (2)$$

x = length (m)

Integrating eq.(2) between x = 0 and X = d yields

$$g*d = {}_{x=0}\int^{x=d} -\delta_v(v) * \delta v/\delta x * dx \quad (3)$$

Derivation with respect to the humidity by volume v_1 is as follows after simplification

$$\delta_v(v = v_1) = d * \delta g/\delta v_1(v = v_{1i}) \quad (4)$$

A complete deduction is given in APPENDIX 1, which is from Nilsson (1980). Nilsson uses vapour pressure (p) instead of humidity by volume.

Eq.(4) means that by a series of measurements with a constant climate at one side and gradually higher humidity by volume v_{1i} at the other, the effect of moisture on the moisture permeability can be measured at discrete humidity by volume and not only the mean value during an interval.

In FIG 3 the moisture flow rate is shown as a function of humidity by volume at the bottom side of the sample. The higher v is the higher is the moisture flow rate. The moisture permeability is achieved by determining the slope of the curve in FIG 3 for different humidities. When the temperature during the test is constant we can use RH instead of v.

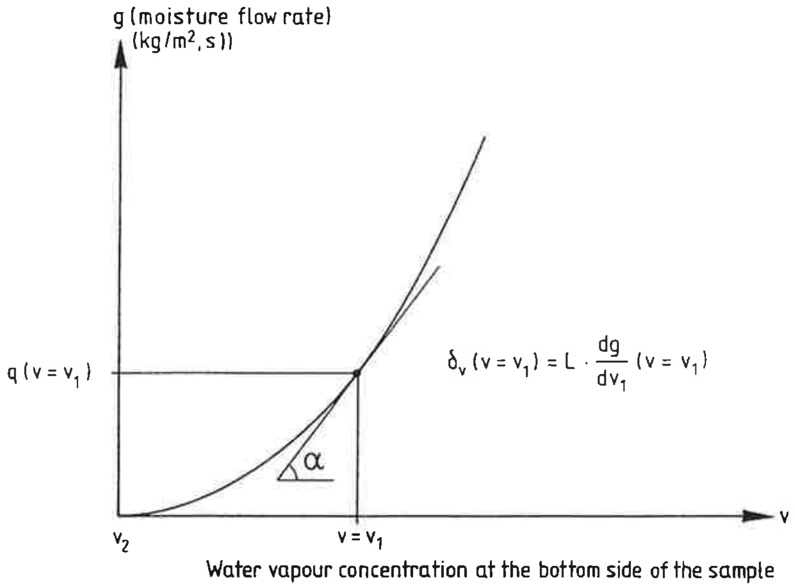


FIG 3 Determination of the moisture permeability.

The moisture flow rate (g) * the thickness (d) of the sample is called the fundamental flow potential (Ψ). The fundamental flow potential is used in the section **Results**, but as the thicknesses of the samples are equal, the fundamental flow potential is in principle the moisture flow rate. The Ψ-potential is used in some computer programs.

Experimental arrangement

The variation of δ_v as a function of RH between about 35 to 100 % has been investigated with the cup method mentioned above. RH outside the cups is about 35 % and RH inside the cups is about 60, 75, 82, 85, 90, 95, 98 and 100 %. These RHs are brought about with saturated salt solutions (exept 100 %). A cup is shown in FIG 4.

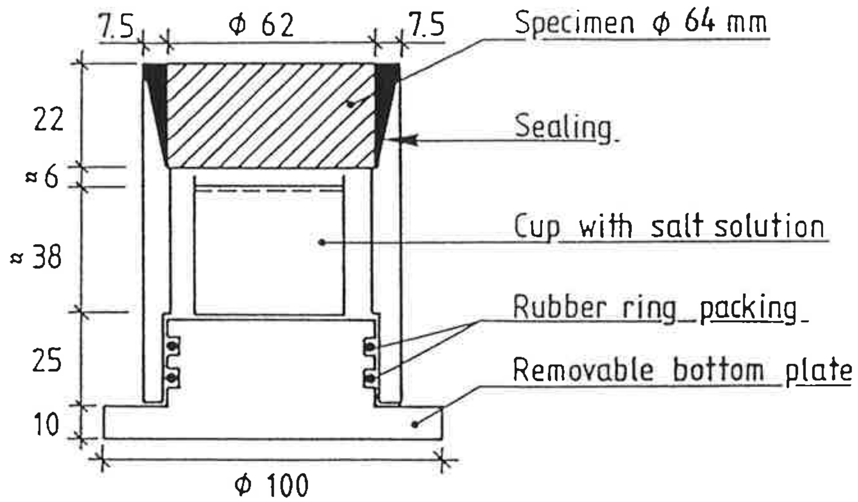


FIG 4 Moisture permeability cup.

The bottom of the cup is removable, and liquid can be refilled up in the cup. This means that the liquid surface in the cup can be nearly constant and close to the bottom side of the sample (about 7 to 10 mm). This is important for open materials. If the distance between the sample and the liquid surface is increased, the moisture resistance of the air gap could be big compared to the moisture resistance of the sample. RH on the bottom side of the sample could then be much lower than the RH of the salt solution. During the evaluation of the results, the moisture resistance of the air gap, has been considered.

Results

The moisture permeability has been determined for clay brick and lime sandstone. The materials are on their absorption isotherm. FIG 5 to

FIG 7 present the measured results for clay brick.FIG 5 shows the fundamental flow potential (Ψ) as a function of RH.

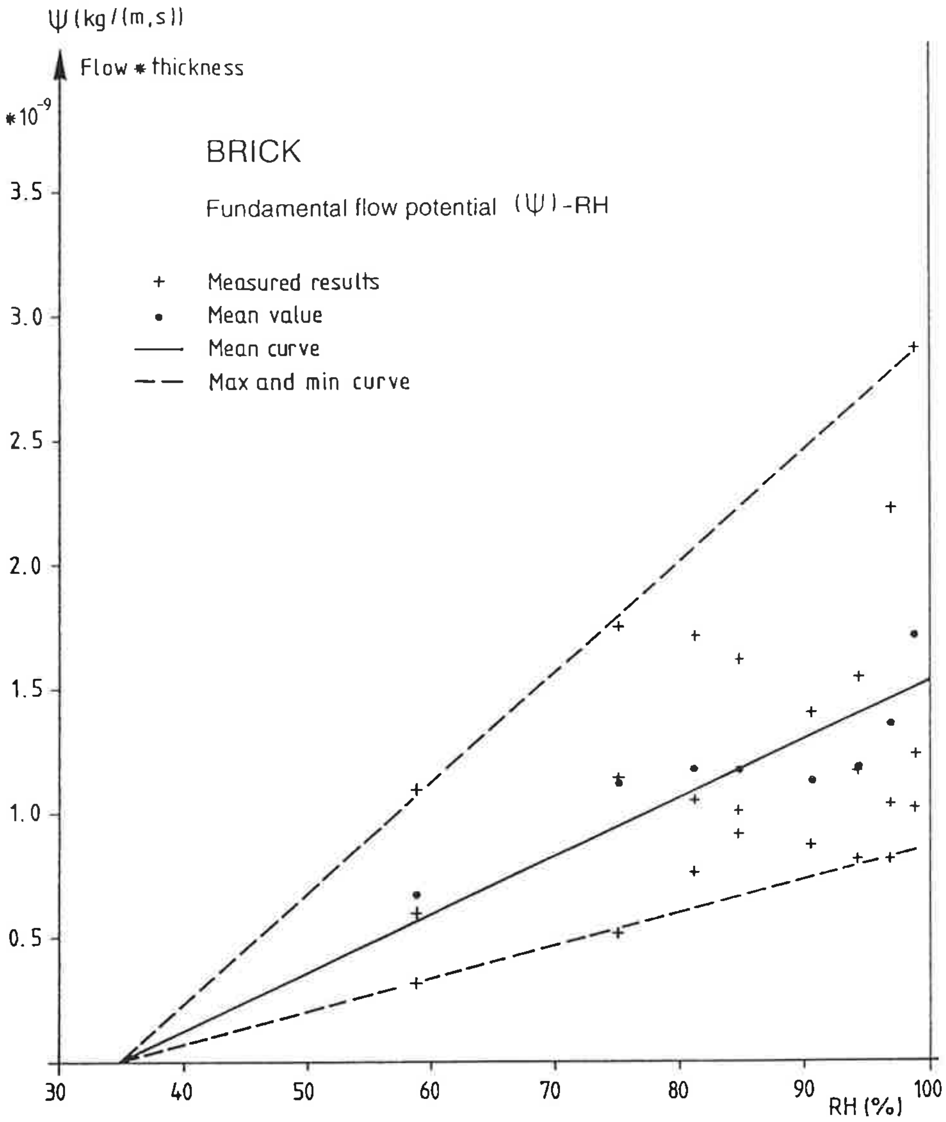


FIG 5 Brick. The fundamental flow potential as a function of the relative humidity (RH).

All measured results are shown in FIG 5. The spread in the results is big. If it is assumed that the moisture permeability does not depend on RH, but on the depth from the surface of the clay brick, we get FIG 6 and FIG 7. On the x-axis is the specimen number, and number 1 is the specimen that includes the clay brick surface. Specimen number 6 or 7 is located in the middle of the clay brick and number 11 or 12 is close to the other surface of the clay brick. In FIG 6 it is clearly shown that δ_v depends on the location in the clay brick. δ_v in the middle of the stone is higher than δ_v at the surface. For specimen 5A-- , FIG 6, the quotient between δ_v in the middle and δ_v at the surface is about 3.

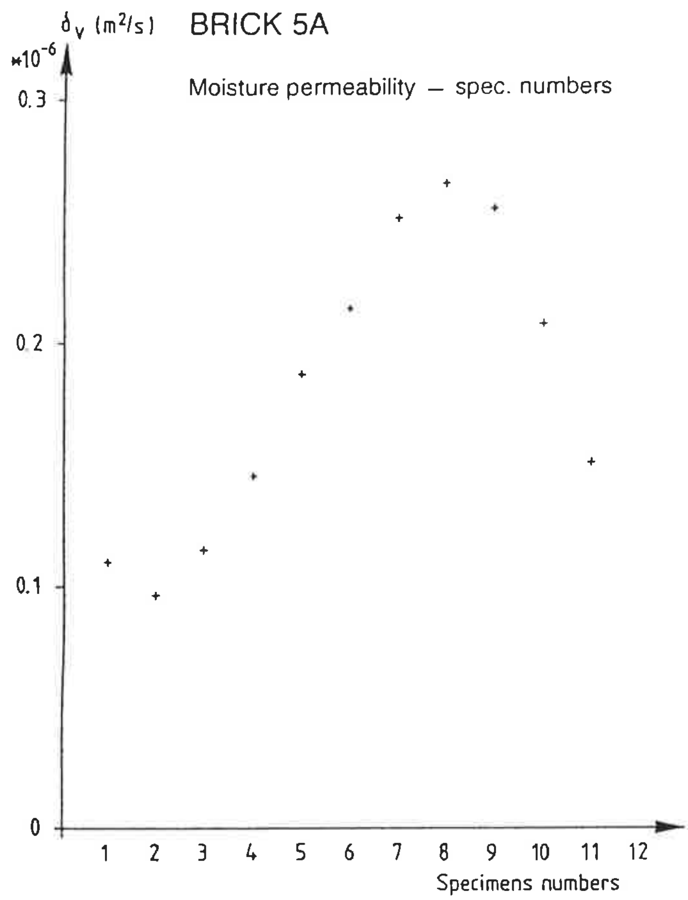


FIG 6 Brick. Moisture permeability for brick 5A.

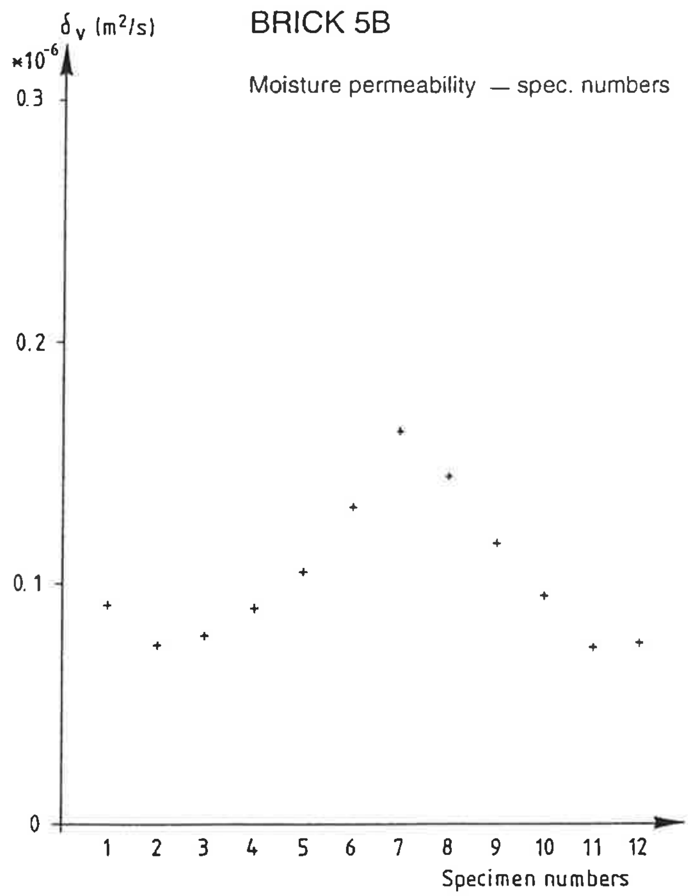


FIG 7 Brick. Moisture permeability for brick 5 B.

The results for lime sandstone are shown in FIG 8 to FIG 11. In FIG 8 the measured results of the fundamental flow potential are shown as a function of RH.

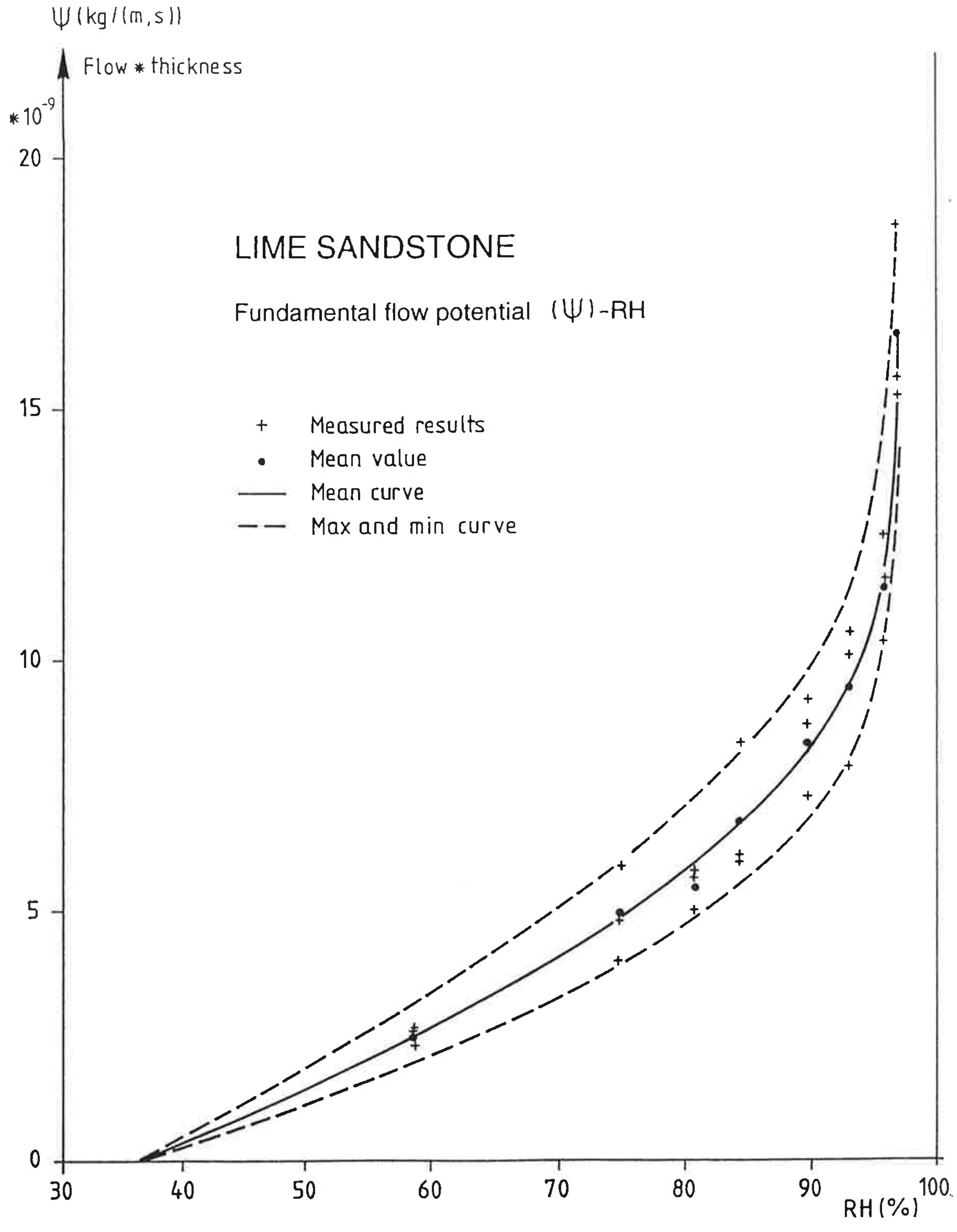


FIG 8 Lime sandstone. The fundamental flow potential as a function of the relative humidity.

Over about 90 % RH there is a strong increase in Ψ (or the moisture flow). When Ψ is drawn as a function of the dry density of the lime sandstone we get FIG 9.

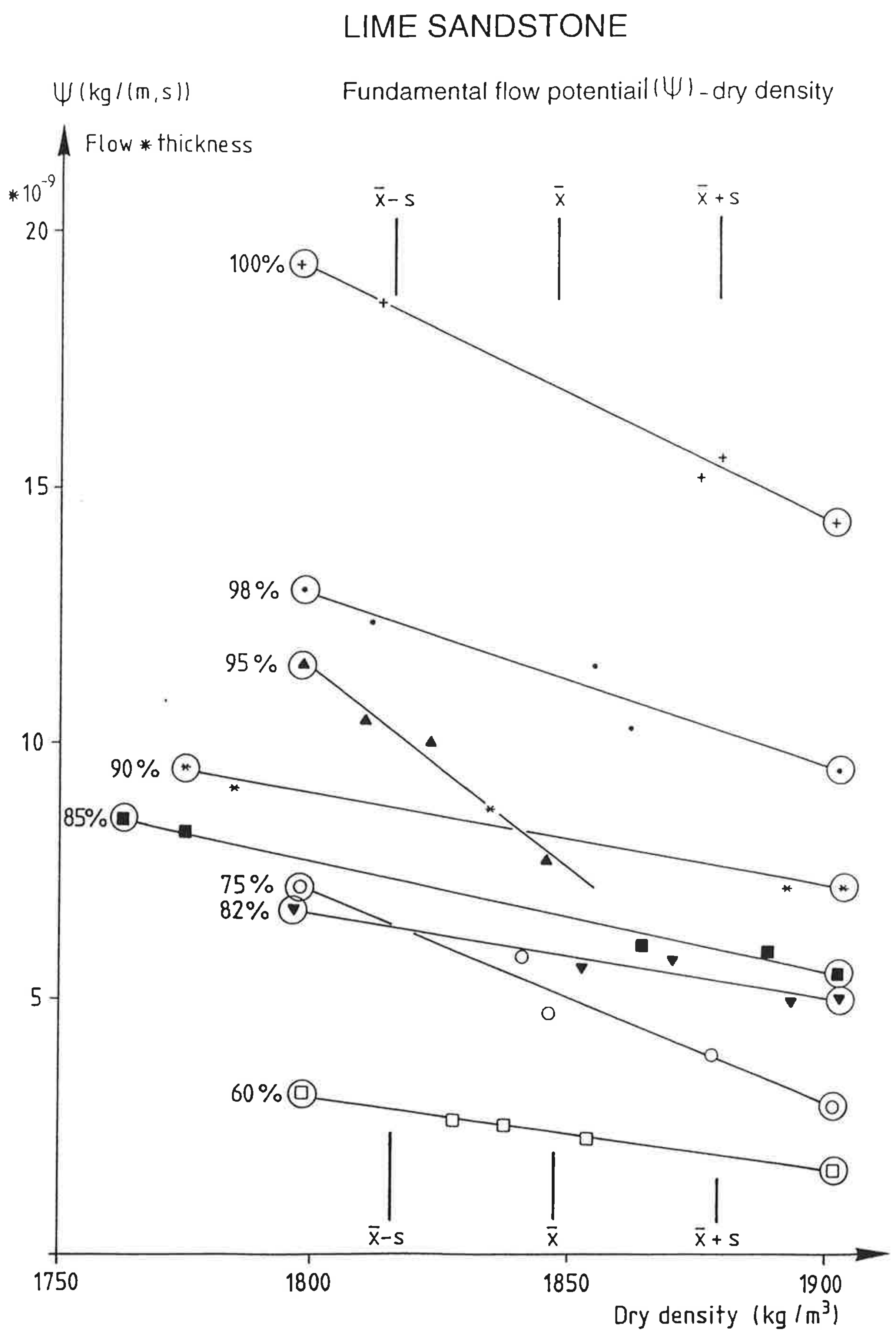


FIG 9 Lime sandstone. The fundamental flow potential as a function of the dry density.

Linear regression is made for the specimens with the same RH on the bottom side of the specimen. In FIG 9 it is seen that the higher the density, the lower is Ψ (for specimens with the same RH in the cup). The mean dry density for the specimens made of lime sandstone is 1847 kg/m^3. When the fundamental flow potential is read on the lines of linear regression for the densities 1815, 1847 and 1879 kg/m^3, FIG 10 is obtained. In FIG 10 Ψ is shown as function of RH and the dry density.

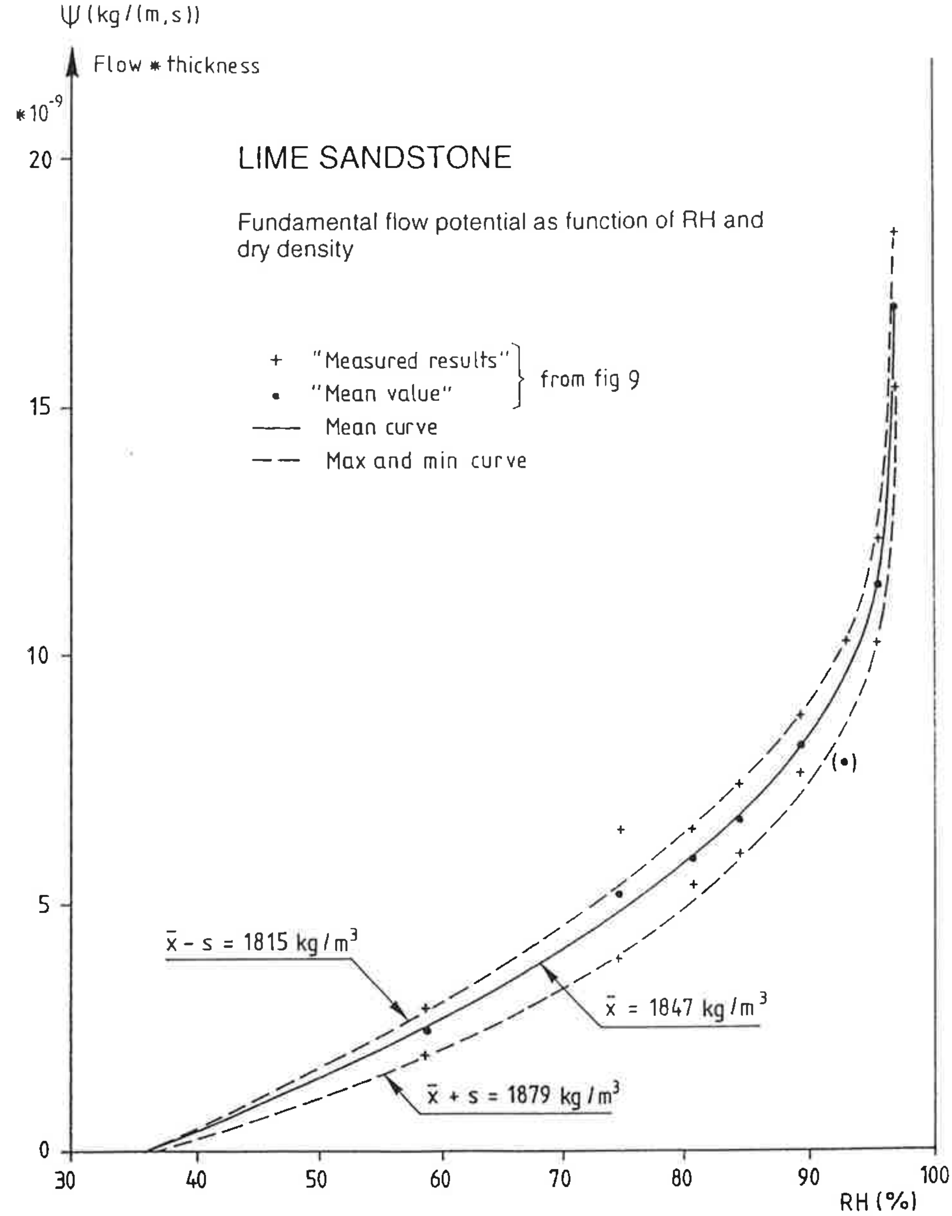


FIG 10 Lime sandstone. The fundamental flow potential as function of the relative humidity and the dry density. From FIG 9.

In FIG 10 it is seen that there is a dependence of the dry density (or porosity) on the fundamental flow potential. In FIG 11, δ_v is shown as a function of RH.

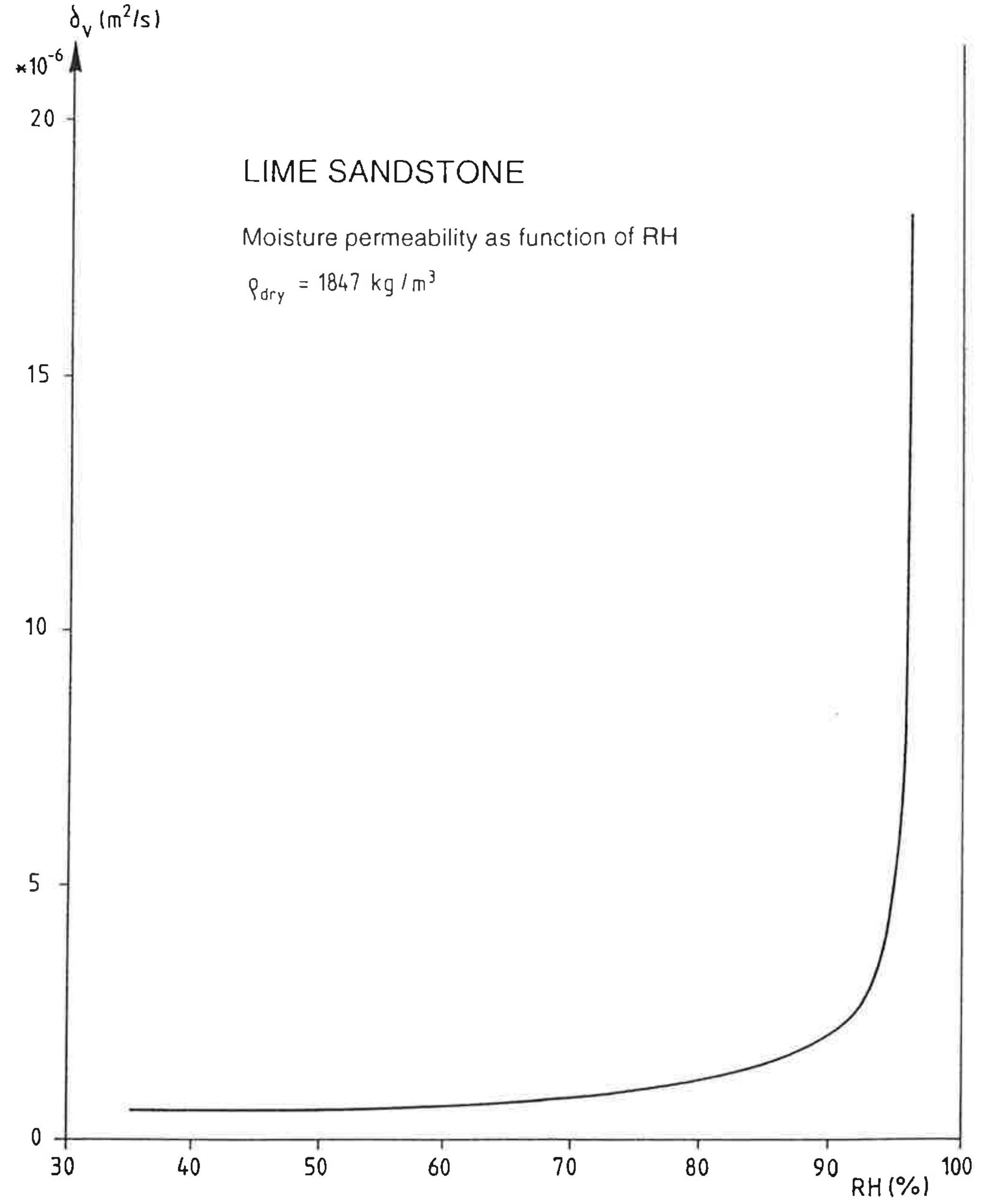


FIG 11 Lime sandstone. The moisture permeability as a function of the relative humidity. Dry density 1847 kg/ m^3.

In FIG 11 it is seen that from about 50 % RH there is an increase in the moisture permeability. From about 90 % RH there is a considerable increase in δ_v.

Future work

We are now determining the moisture permeability for clay brick and lime sandstone under desorption. When the specimens made of cement paste have arrived we have to "build" special equipment for these specimens.

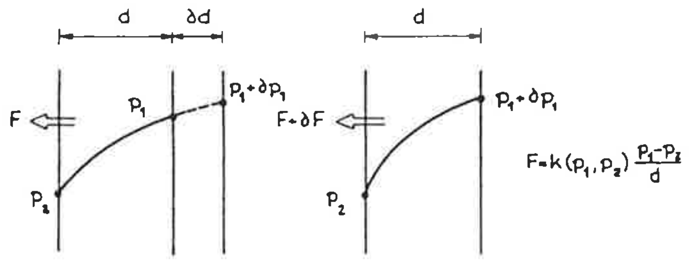
References

Bazant, Z. P. & Najjar, L. J. (1972) Nonlinear water diffusion in nonesaturated concrete, Matr. & Constr. Vol.5 No 25, pp 3-20.

Nilsson, L-O. (1980) Hygroscopic Moisture in Concrete - Drying, measurements and related material proporties. Lund Institute of Technology, Division of Building Materials, Lund, Report TVBM-1003.

Appendix 1

The equation (5:5) can be deducted by studying <u>two</u> plates; one plate with a thickness d, with a vapour pressure of $p_2 + \partial p_1$ on one side and a constant pressure p_2 on the other; <u>one</u> plate with the same vapour pressure as the other plate, but a thickness of $d + \partial d$ in such a way that the vapour pressure is p_1 at a depth of d, cf. the figures below.



The flow through the thicker plate becomes

$$F = k(p_1 + \partial p_1, p_2) \frac{p_1+\partial p_1 - p_2}{d+\partial d} \qquad (1)$$

Through the thinner plate one obtains a flow of

$$F + \partial F = k(p_1 + \partial p_1, p_2) \frac{p_1+\partial p_1 - p_2}{d} \qquad (2)$$

(1) & (2) give

$$F + \partial F = F \frac{d+\partial d}{d} = F + F \frac{\partial d}{d}$$

i.e.

$$\partial F = F \frac{\partial d}{d} \qquad (3)$$

The flow through the thicker plate is also obtained from

$$F = k(p_1 + \partial p_1, p_1) \cdot \frac{\partial p_1}{\partial d} \qquad (4)$$

(3) & (4) give

$$\partial F = k(p_1 + \partial p_1, p_1) \cdot \frac{\partial p_1}{\partial d}$$

or

$$d \frac{\partial F}{\partial p_1} = k(p_1 + \partial p_1, p_1) \qquad (5)$$

When ∂p_1 (and ∂d) approaches 0 one obtains

$$d \frac{\partial F}{\partial p_1} = k(p_1) \qquad \text{eq. (5:5)}$$