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## SCIENCE - project CT91-0737 : annual report from Lund Institute of Technology

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Division of Building Materials

## **SCIENCE - project CT91-0737**

ANNUAL REPORT FROM LUND INSTITUTE OF TECHNOLOGY

by

Göran Hedenblad

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REPORT TVBM-7074  
Lund, Sweden, March 1994

## Annual report from Lund Institute of Technology

### Background

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

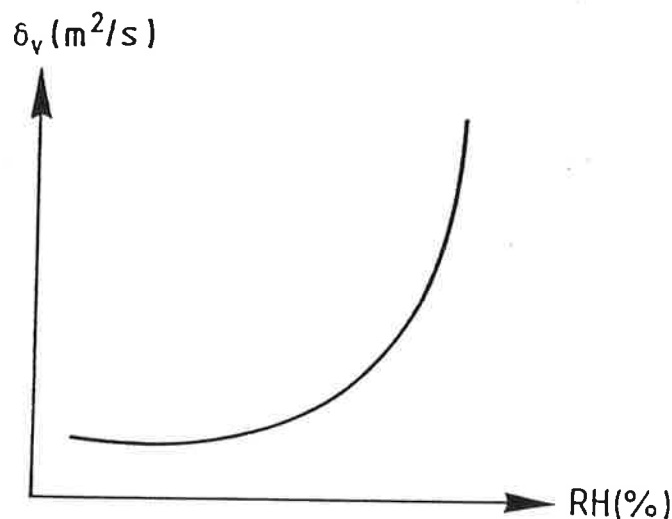


FIG 1. Moisture permeability (with the humidity by volume as potential) as a function of the relative humidity. In principle.

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

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

$g$  = vector density of moisture flow rate (kg/(m<sup>2</sup>,s))

$v$  = humidity by volume in the pores of the specimen (kg/m<sup>3</sup>)

$\delta_v$  = moisture permeability with regard to humidity  
by volume ( $\text{m}^2/\text{s}$ )

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

$\delta_v$  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  $\delta_v$  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.

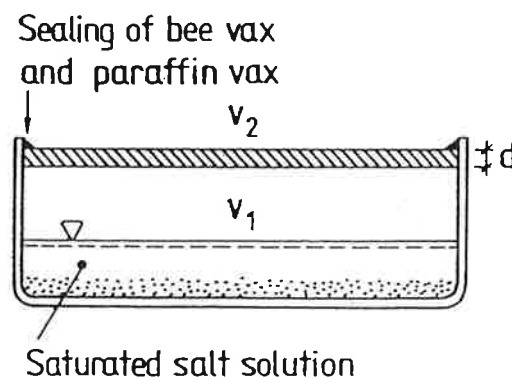


FIG 2 Principle of diffusion measurements with the cup method.

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

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

$$x = \text{length} \quad (m) \quad (3)$$

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

$$g \cdot d = \int_{x=0}^{x=d} -\delta_v(v) \cdot \delta v / \delta x \cdot dx \quad (4)$$

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

$$\delta_v(v = v_i) = d \cdot \delta g / \delta v (v = v_i) \quad (5)$$

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  $v_i$  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  $v$ .

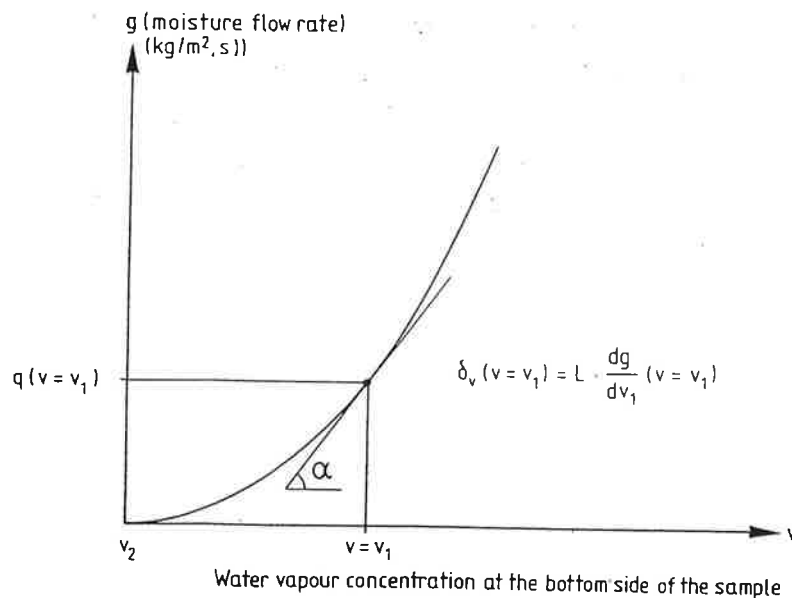


FIG 3 Determination of the moisture permeability.

The moisture flow rate (g) \* the thickness (d) of the sample is called the fundamental flow potential ( $\Psi$ ). 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  $\Psi$ -potential is used in some computer programs.  $\Psi$  is also called the Kirchoff flow potential.

## Experimental arrangement

The variation of  $\delta_v$  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 (except 100 %). A cup is shown in FIG 4.

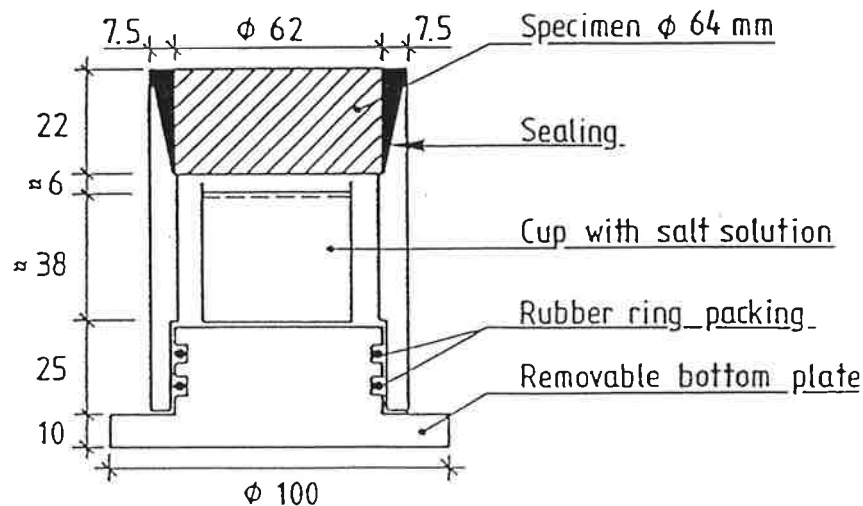


FIG 4 Moisture permeability cup.

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

All the results, so far, are reported here, also the results obtained during 1992-1993.

The moisture permeability has been determined for clay brick, lime sandstone and cement pastes. FIG 5 to FIG 7 present the measured results for clay brick. FIG 5 shows the fundamental flow potential ( $\Psi$ ) as a function of RH. The material in FIG 5 is on its absorption isotherm.

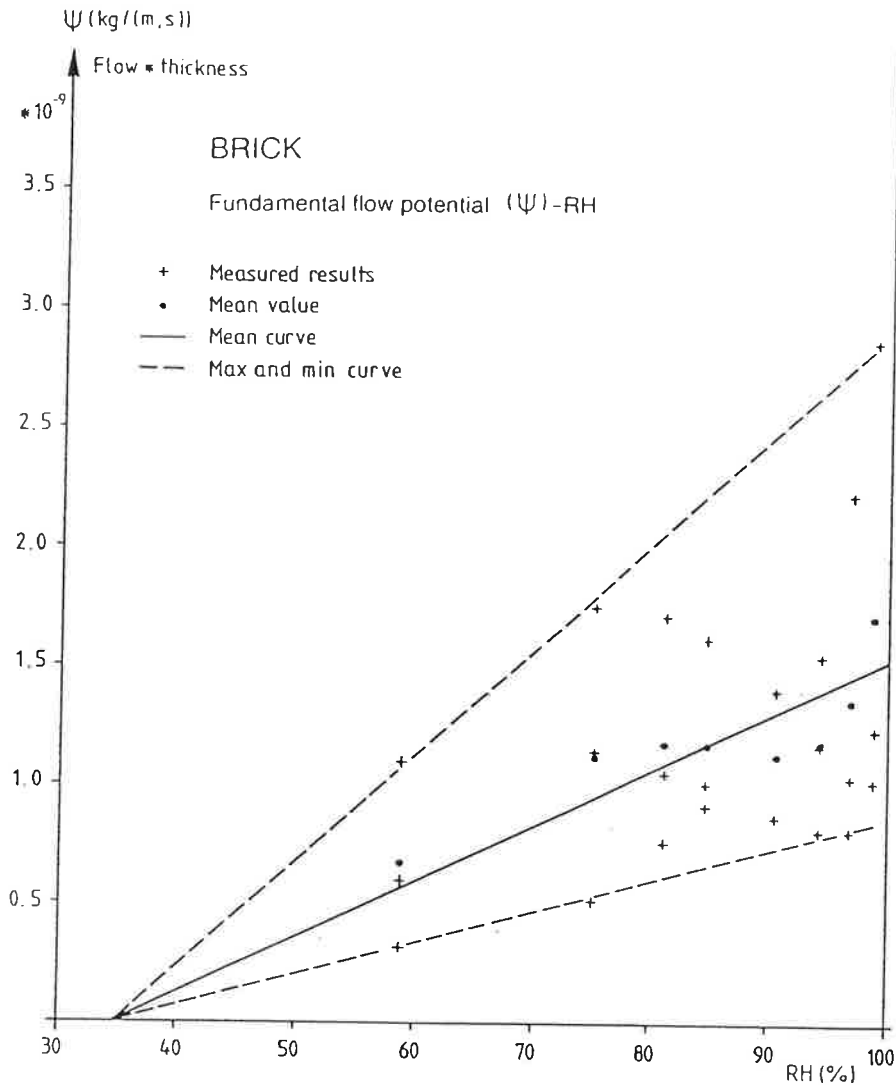


FIG 5 Brick. The fundamental flow potential as a function of the relative humidity (RH). Absorption.

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  $\delta_v$  depends on the location in the clay brick.  $\delta_v$  in the middle of the stone is higher than  $\delta_v$  at the surface. For specimen 5A-- , FIG 6, the quotient between  $\delta_v$  in the middle and  $\delta_v$  at the surface is about 3. The difference in  $\delta_v$  is small for the clay brick if it is on its absorption or desorption isotherm.

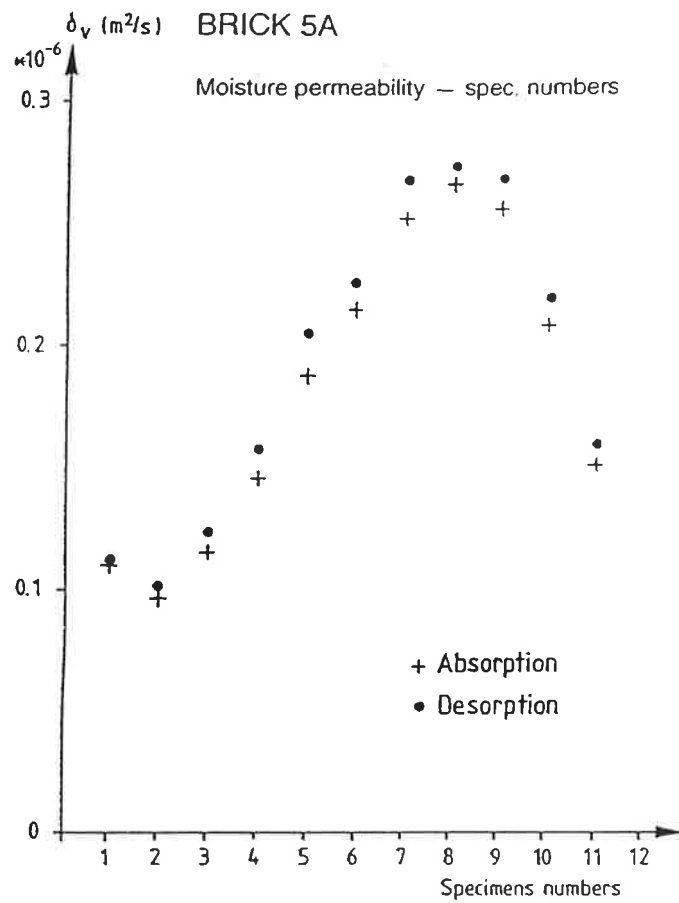


FIG 6 Brick. Moisture permeability for brick 5A.

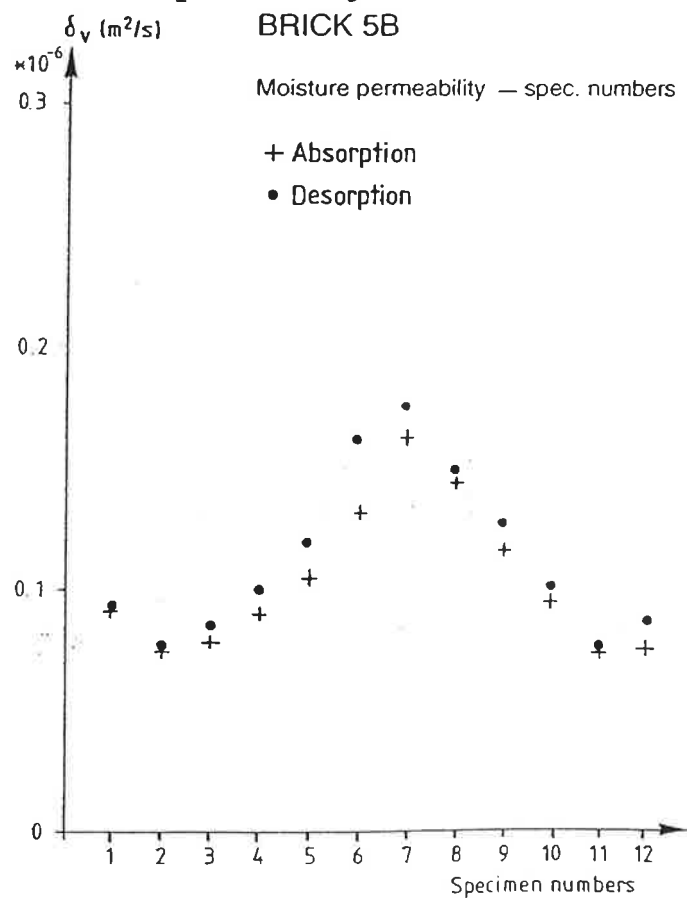


FIG 7 Brick. Moisture permeability for brick 5 B.



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, ( under absorption ).

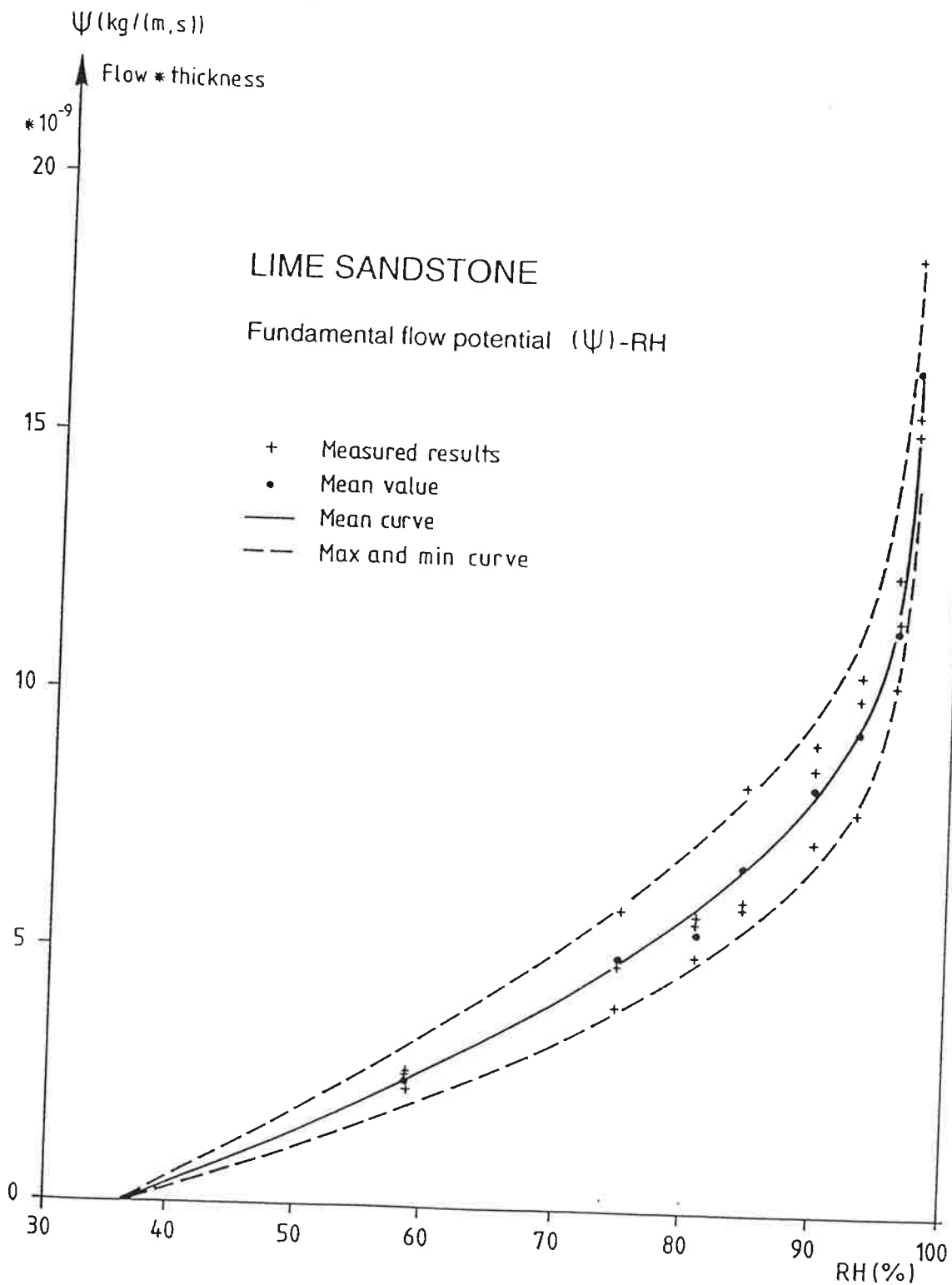


FIG 8 Lime sandstone. The fundamental flow potential as a function of the relative humidity. Absorption.

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

## LIME SANDSTONE

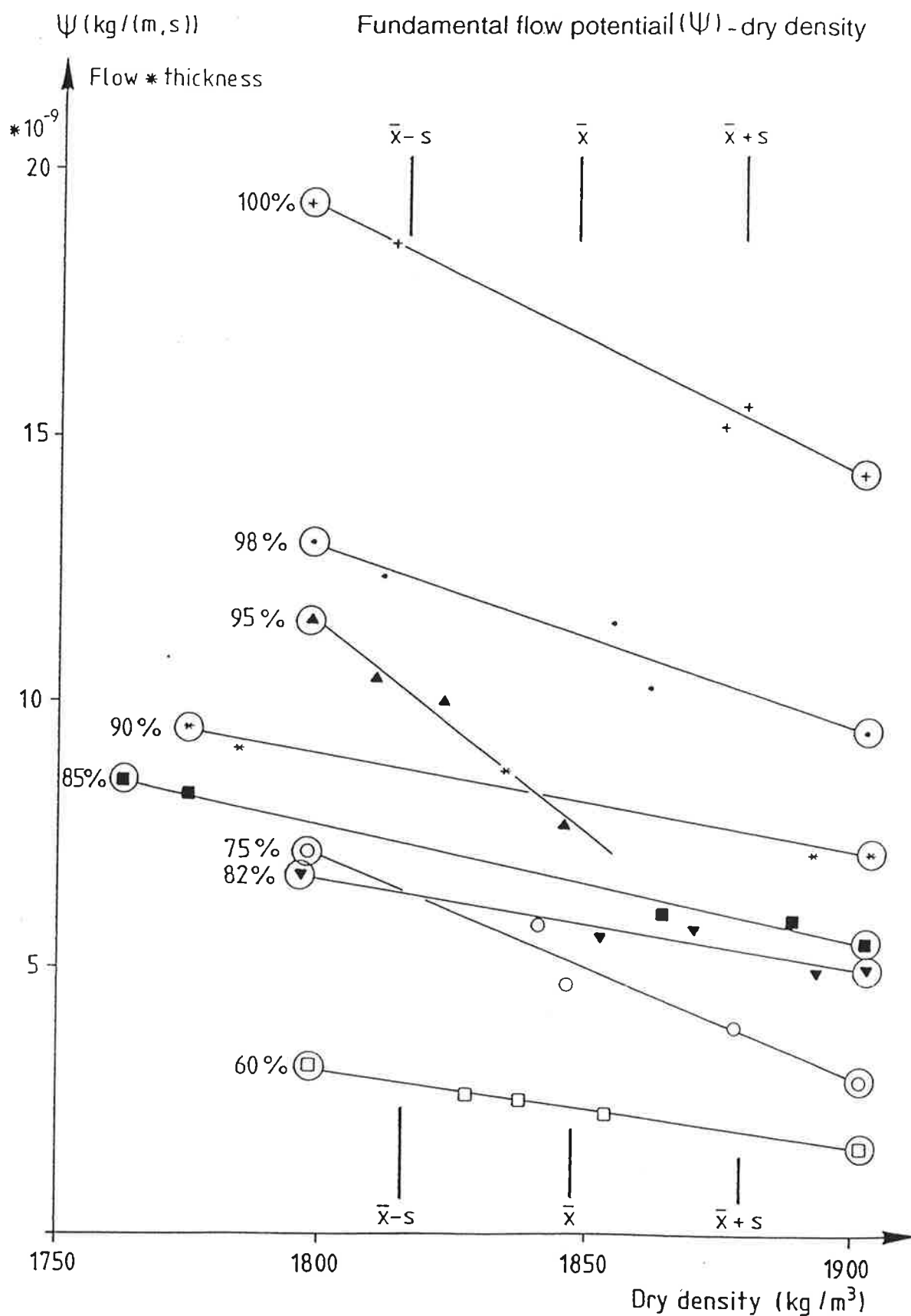


FIG 9 Lime sandstone. The fundamental flow potential as a function of the dry density. Absorption.

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  $\Psi$  (for specimens with the same RH in the cup). The mean dry density for the specimens made of lime sandstone is  $1847 \text{ kg/m}^3$ . When the fundamental flow potential is read on the lines of linear regression for the densities  $1815$ ,  $1847$  and  $1879 \text{ kg/m}^3$ , FIG 10 is obtained. In FIG 10  $\Psi$  is shown as function of RH and the dry density.

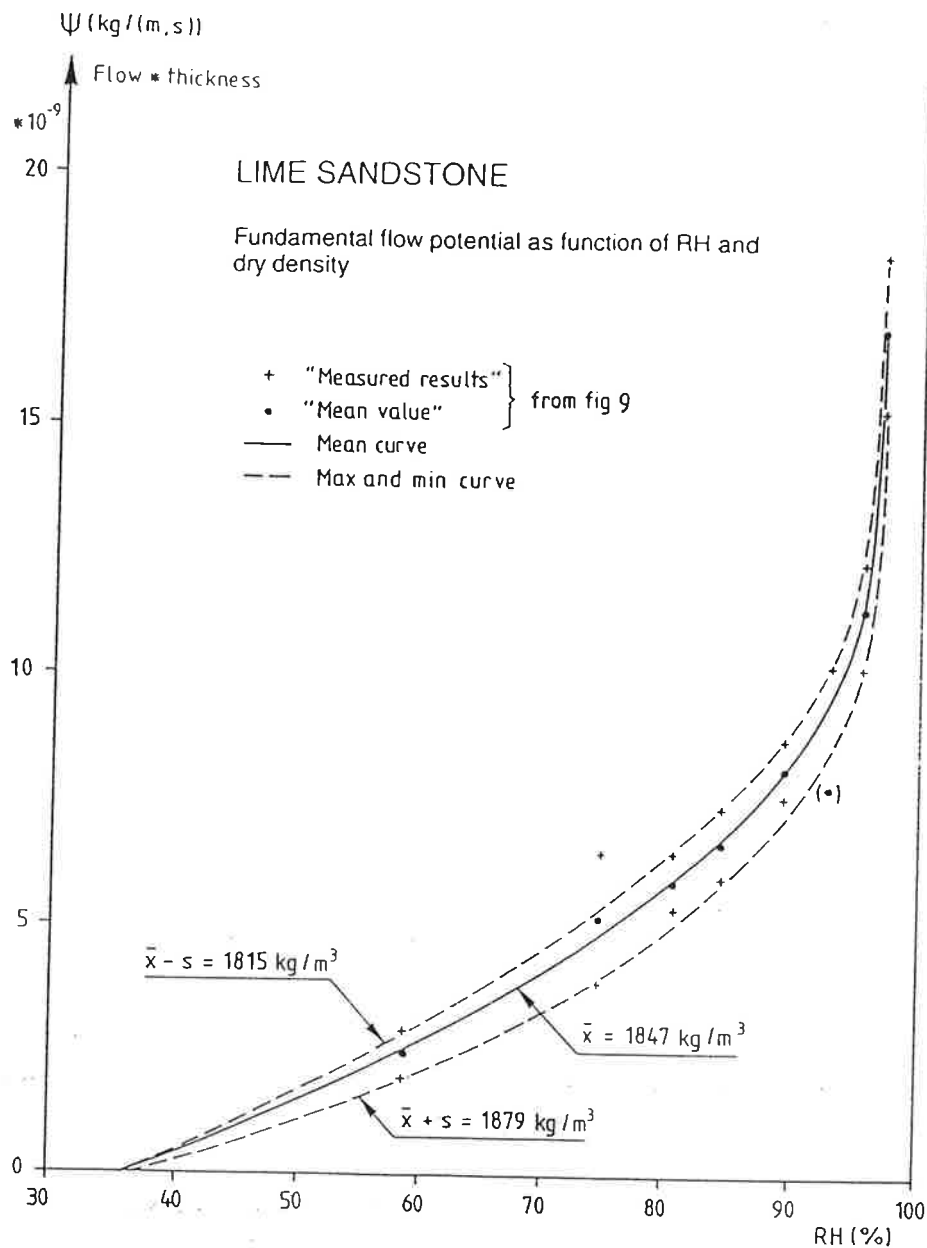


FIG 10 Lime sandstone. The fundamental flow potential as function of the relative humidity and the dry density. From FIG 9.

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,  $\delta_v$  is shown as a function of RH.

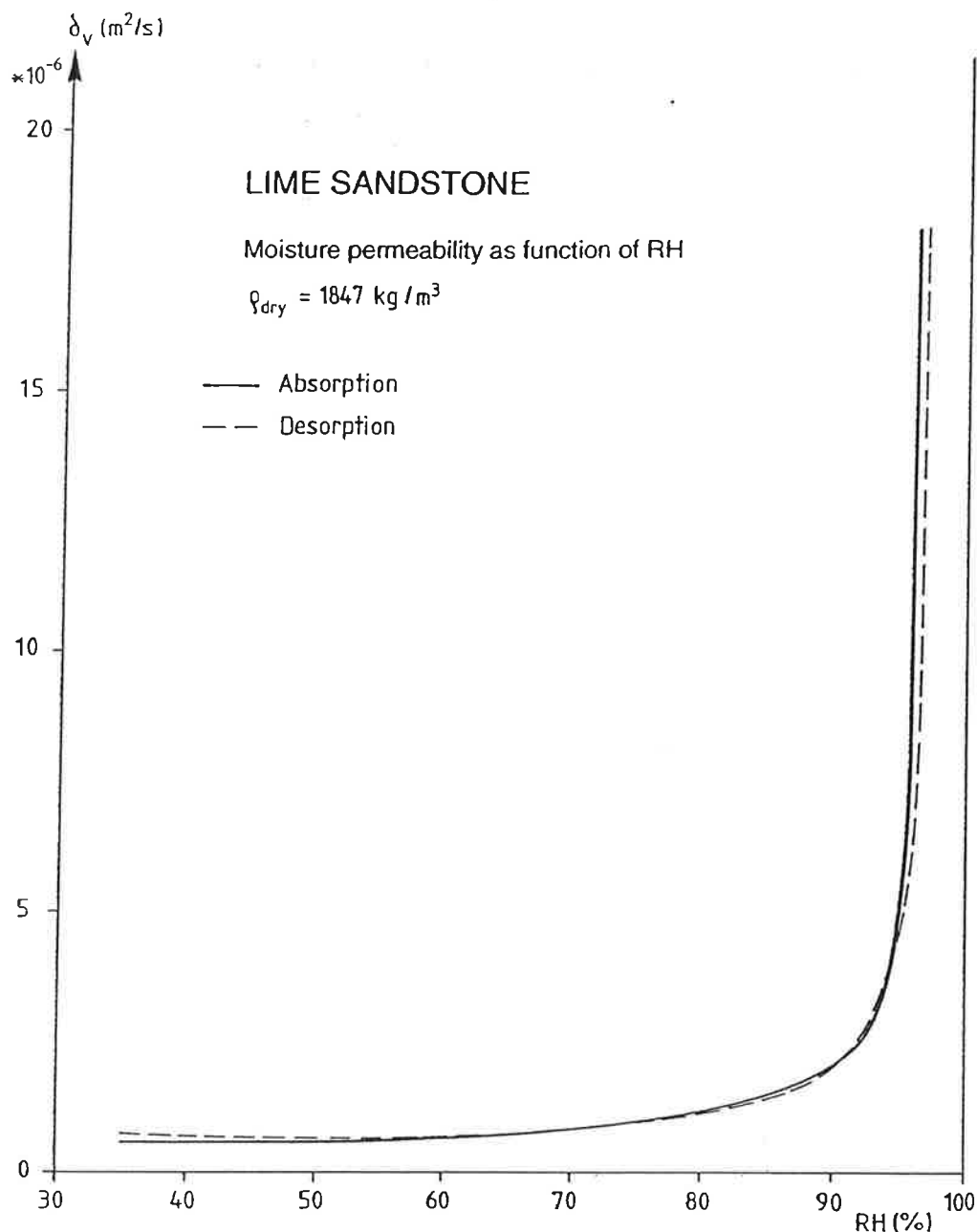


FIG 11 Lime sandstone. The moisture permeability as a function of the relative humidity. Dry density  $1847 \text{ kg/m}^3$ .

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  $\delta_v$ . The difference in  $\delta_v$  is small for the lime sandstone between absorption and desorption.

The results for 4 different cement pastes are shown in FIG 12, which shows the moisture permeability as a function of RH.

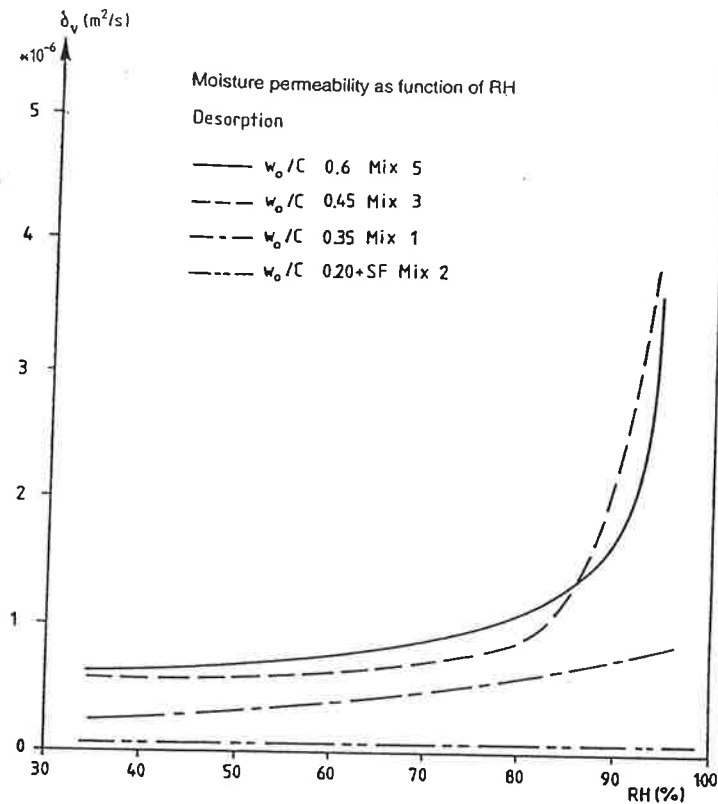


FIG 12 Cement pastes. The moisture permeability as a function of the the relative humidity.

In FIG 12 it is shown that  $\delta_v$  for cement paste with  $w_o/C$  0.2 and with silica fume is much lower than for the other cement pastes.

In FIG 13  $\delta_v$  is shown for cement paste with  $w_o/C$  0.35.

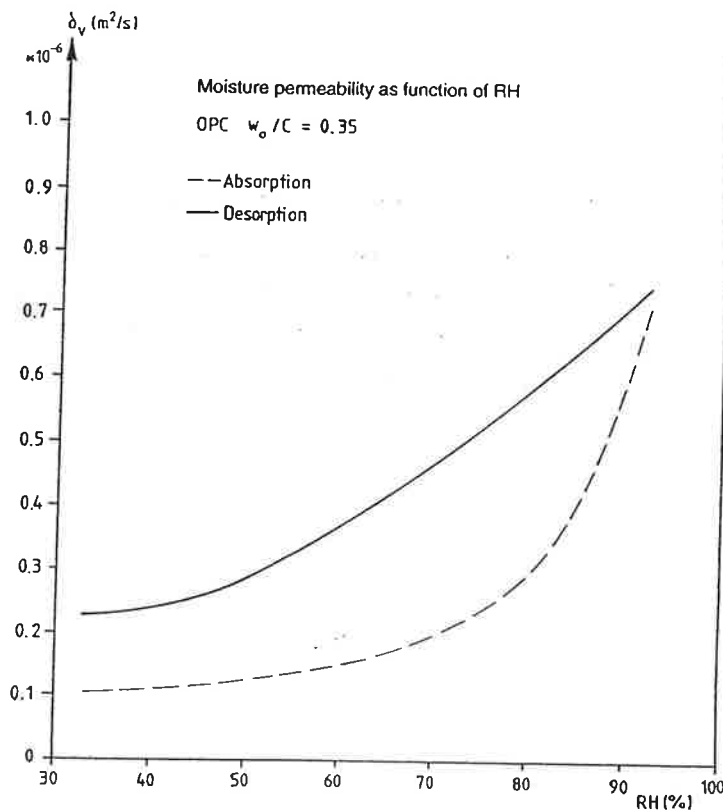


FIG 13 Cement paste with  $w_o/C$  0.35. The moisture permeability as a function of the relative humidity.

FIG 13 shows that up to about 90 % RH there is a difference in  $\delta_v$  if the material is under absorption or if it is under desorption.

In FIG 14  $\delta_v$  is shown for cement paste with  $w_o/C$  0.6.

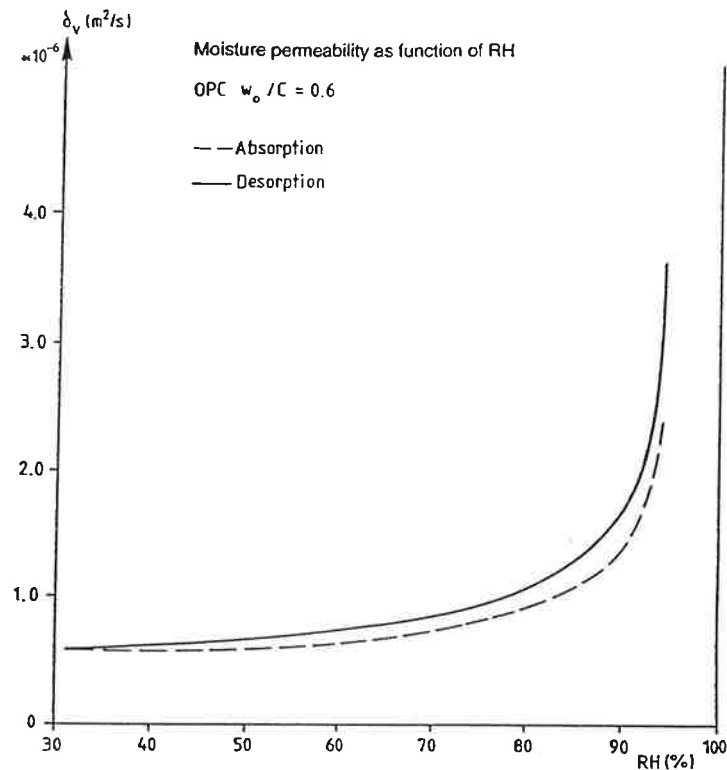


FIG 14 Cement paste with  $w_o/C$  0.6. The moisture permeability as a function of the relative humidity.

FIG 14 shows that the difference in  $\delta_v$  is rather small if the material is under absorption or desorption.

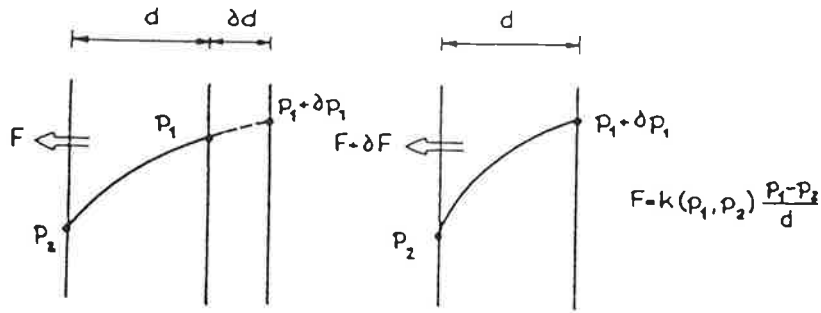
For the cement pastes the  $\Psi$ - potential is not shown here because there is only one specimen for each climate. Then the spread in the results for each climate can not be seen. The reason for only one specimen per climate is that the specimens are much smaller for cement paste and we could not use the same equipment as for the other materials.

## 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 properties. Lund Institute of Technology, Division of Building Materials, Lund, Report TVBM-1003.

## Appendix 1

The equation (5:5) can be deduced by studying two 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; one 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

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

Through the thinner plate one obtains a flow of

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

(1) & (2) give

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

i.e.

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

The flow through the thicker plate is also obtained from

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

(3) & (4) give

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

or

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

When  $\partial p_1$  (and  $\partial d$ ) approaches 0 one obtains

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