# Measurement of the Moisture Storage Capacity Using Sorption Balance and Pressure Extractors

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**ABSTRACT:** This paper presents measurements of the moisture storage capacity for several different porous building materials. The storage capacity is measured by a sorption balance in the hygroscopic range and with pressure plate and pressure membrane extractors in the superhygroscopic range. The results are presented both as retention curves and sorption isotherms and indicate, among other things, that some materials have a large hysteresis between absorption and desorption in the superhygroscopic range. This is contrary to what sometimes has been postulated.

**KEY WORDS:** moisture storage capacity, water retention curves, suction, sorption balance, pressure plate extractor, pressure membrane extractor.

## INTRODUCTION

STRUCTURES, AND CONSEQUENTLY all building materials used in structures, are always in contact with moisture, either in the form of vapor in the ambient air or as liquid. Consequently porous building materials will always contain a certain amount of moisture, physically bound in the pore structure.

The moisture bound in a material directly affects material properties, such as strength, shrinkage, and thermal conductivity. Moisture in porous building materials also plays an important role in almost all durability problems. In many cases, it is the direct cause of damage. Moisture is also important in a

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variety of other degradation processes in which it serves as a catalyst (e.g., in the emission of unhealthy substances from flooring materials). Society incurs considerable costs each year because of moisture-related durability problems.

It is therefore essential to have models of moisture and liquid (capillary) transport and of corresponding transport properties, such as moisture diffusivity and moisture storage capacity. Moisture storage capacity is of particular importance when calculating moisture transport in multi-layer constructions because it is required for a prediction of the moisture status at the interface between materials.

## MOISTURE FIXATION

### General

Water can be bound in porous materials in several different ways, both physical and chemical. In contact with moist air, water molecules are physically bound to the surface of the pore system until equilibrium with the humidity of the ambient air is reached. Chemically bound water only exists in materials, such as those that are cement based, in which some of the mixing water is bound in the cement gel. Chemically bound water can be removed by heating to very high temperatures.

Water can be bound physically by adsorption and surface tension phenomena such as capillary condensation and capillary water uptake. Adsorbed water molecules are bound to the pore surface by van der Waals forces. At equilibrium the amount of adsorbed water per square meter of pore surface is a function of the temperature and the relative humidity of the ambient air. The condition is never static; some water molecules leave the pore surface, other water molecules become attached. At equilibrium, the number of molecules leaving is the same as the number becoming bound to the surface.

Capillary condensation of water molecules occurs on curved water menisci that are formed in small pores and other narrow spaces. Theoretically there is no upper moisture level for capillary condensation but normally this phenomenon is supposed to be restricted to the so-called hygroscopic range while capillary water uptake occurs in the superhygroscopic range. The relationship between the relative humidity, $\phi$, when condensation takes place and the principal radii of the curvature of the meniscus in two orthogonal directions, $r_1$ and $r_2$ (m), is given by Kelvin's equation:

$$\ln\phi = -\frac{\sigma M_w}{RT\rho_w}\left(\frac{1}{r_1}+\frac{1}{r_2}\right) \tag{1}$$

where $\sigma$ is the surface free energy of a surface liquid gas (J/m$^2$), $M_w$ is the molar weight of water (0.018 kg/mol), $R$ is the gas constant [8.314 J/(mol·K)], $T$ is the temperature (K) and $\rho_w$ is the density of water (kg/m$^3$).

Salts dissolved in pore water lower the relative humidity at which capillary condensation takes place. This effect is similar to that occurring for a curved water surface (i.e., the material will absorb more water from the ambient air if salt is present in the pore water).

In the hygroscopic range (i.e., from 0 to approximately 98% relative humidity), the relation between the moisture content of the ambient air and the moisture content of the material represents the moisture storage capacity. This relation is given by sorption isotherms. In the superhygroscopic range, the moisture fixation is often represented by a relation between the suction $s$ (Pa) and the moisture content of the material. (Suction is defined as the pressure difference between the ambient total pressure and the pore water pressure.) This relation is given by what are known as water retention curves.

In sorption isotherms the relative humidity, vapor content, or vapor pressure is plotted against the equilibrium moisture content in the material [in most cases expressed by moisture content mass by mass, $u$ (kg/kg), or moisture content mass by volume, $w$ (kg/m$^3$)]. In retention curves the suction is plotted against the equilibrium moisture content in the material. For many materials there is hysteresis between absorption and desorption (i.e., the relations are different, depending on whether equilibrium is reached by absorption or desorption). The reason for the hysteresis is not completely known, although it is often explained in terms of the classical "ink-bottle" theory. This theory has, however, been questioned, especially for the superhygroscopic range (e.g., see Reference [1]).

The Laplace equation gives the relationship between the suction $s$ (Pa) and the radii of the curvature of the meniscus in two orthogonal directions, $r_1$ and $r_2$:

$$s = \sigma\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \tag{2}$$

Combining Kelvin's equation [Equation (1)] with the Laplace equation [Equation (2)] gives the following relationship between the suction and the relative humidity:

$$\ln\phi = -\frac{s M_w}{RT\rho_w} \tag{3}$$

It is thus possible to represent moisture fixation in both the hygroscopic and the superhygroscopic range in terms of a single relationship using either relative humidity or suction as the measure of moisture storage potential. The use of relative humidity to determine moisture storage potential results in a very steep curve in the superhygroscopic range, meaning that the resolution in this region will be poor. At high moisture levels, it is therefore better to use suction to determine the moisture storage potential, which means using water-retention curves.

If the model of the pore system is based on the assumption that the system consists of cylindrical tubes with varying radii $r$, it is possible to calculate pore size distribution from the moisture storage capacity. In a cylindrical pore the curvature of the meniscus is equal in all directions, that is $r_1 = r_2$. In this case, the relation between the radius of the meniscus and the radius of the tube is:

$$r_1 = r_2 = \frac{r}{\cos\theta} \tag{4}$$

where $\theta$ is the contact angle and $r$ is the pore radius. The contact angle is usually set to 0°. However, this value is probably not valid for many materials. For example, according to Reference [2] the contact angle between a certain type of sand and water is 50°. However, since the cylindrical pore model bears little relation to actual pore geometry in porous building materials, the magnitude of the contact angle is fairly unimportant, for the calculated radius $r$ will never correspond to "true" pore radius.

Using Equations (1) and (4), it is possible to calculate the pore radius from the relative humidity, and consequently it is also possible to obtain the pore size distribution from the sorption isotherm:

$$r = -\frac{2\sigma \cos\theta \, M_w}{\ln\phi \, RT \rho_w} \tag{5}$$

Thus, all pores smaller than $r$ are water filled at equilibrium with a certain relative humidity $\phi$. With the cylindrical pore model it is also possible to calculate pore size distribution from the water retention curve using Equations (2) and (4):

$$r = \frac{2\sigma \cos\theta}{s} \tag{6}$$

The pore radius can be regarded as an additional measure of moisture storage potential. It has the same resolution and advantages as using suction, i.e., the pore size distribution gives good resolution in the superhygroscopic range.

## Methods of Measuring the Moisture Storage Capacity

There are several methods of measuring the moisture storage capacity in the hygroscopic and superhygroscopic range. The classical, and probably most common, method of measuring fixation in the hygroscopic range uses different saturated salt solutions. Specific levels of relative humidity exist above saturated salt solutions in closed climate boxes. The sorption isotherm can be measured by placing specimens of a material in boxes with different saturated salt solutions, each one corresponding to different relative humidity, and weighing the specimens when equilibrium is reached. The method is robust and relatively simple, but also quite time-consuming. Depending on the material and the size of the specimen, the experimental time may vary from a month to a year.

Faster methods of measuring sorption isotherms exist. One possibility involves using a twin double microcalorimeter. A detailed account of this method is given in References [3] and [4]. Yet another approach to measuring moisture storage capacity in the hygroscopic range involves using a sorption balance. This method was used to obtain the isotherms presented in this paper and is described in detail in the Materials and Methods section. A review of other methods of measuring the moisture storage capacity in the hygroscopic range can be found in Reference [5].

There is no established method of determining moisture storage capacity in the superhygroscopic range, for saturated salt solutions cover only the hygroscopic range. However, a technique using pressure plate or pressure membrane extractors can be used. A standard method for using this technique has existed since 1997 which can be seen in Reference [6] (Nordtest Standard NT BUILD 481). This technique, too, is described in detail in the Materials and Methods section.

Since Equation (6) enables calculation of pore size distributions from water retention curves, the reverse procedure is obviously also possible. Thus, if the pore size distribution can be measured, the moisture storage capacity can be calculated. The most frequently used method of measuring pore size distributions is probably mercury intrusion porosimetry. A comparison between moisture storage capacity measured with pressure plate/membrane extractors and mercury intrusion porosimetry is made in Reference [7], and fairly good agreement is shown for the tested sandstone. It is also possible to obtain pore size distributions, and thereby also moisture storage capacity, from other types of measurements (such as freezing-point depression [8]), which are reviewed in Reference [9].

## MATERIALS AND METHODS

### General

The building materials tested were autoclaved, aerated concrete; cement mortar ($w_0/C = 0.8$); cement-lime mortar CL 50/50/650; lime silica brick; and two types of bricks, “Kanik Antik” (red) and “Kanik Gul” (yellow and hard-burned). A Gotland sandstone (named Uddvide) was also tested which is soft and therefore easy to work. It was often used in sculptural decorations and facings on churches, castles, and private dwellings during the seventeenth and eighteenth centuries. This sandstone is one of the predominant materials in existing historical buildings in the Baltic region [10].

## Determination of Density, Porosity and Sorption Coefficient

The porosity, density, and sorption coefficient were measured in order to characterize the materials. The density was calculated as the ratio of the dry weight to the specimen volume. Archimedes' principle was used to determine volume, with the specimen being vacuum saturated with water and weighed in air and in water. The volume and density were then calculated from:

$$V = \frac{m_{air} - m_w}{\rho_w} \tag{7}$$

$$\rho = \frac{m_0}{V} \tag{8}$$

where $V$ is the specimen volume (m$^3$), $m_{air}$ is the vacuum-saturated specimen weight in air (kg), $\rho_w$ is the density of water (kg/m$^3$), $\rho$ is the density of the specimen (kg/m$^3$), $m_w$ is the vacuum-saturated specimen weight in water (kg), and $m_0$ is the dry weight (kg). Vacuum saturation was performed using a procedure described in Reference [11].

The weighing in air and water also enables determination of the porosity, $P$ (m$^3$/m$^3$):

$$P = \frac{m_{air} - m_0}{\rho_w V} \tag{9}$$

The sorption coefficient $A$ [kg/(m$^2$ s$^{½}$)] is defined by:

$$W = A\sqrt{t} \tag{10}$$

where $W$ is the amount of absorbed water (kg/m$^2$) and $t$ is the time (s) the sample is exposed to a free water surface. The sorption coefficient was evaluated from capillary water uptake tests. These tests were performed on specimens dried in a normal indoor climate. The amount of absorbed water per square meter was plotted as a function of the square root of time (see Figure 1). The slope of the line up to capillary saturation ($W_{cap}$) at the time ($t_c$) of the function gives the sorption coefficient.

## Determination of the Moisture Storage Capacity in the Hygroscopic Range with a Sorption Balance

### *LABORATORY SET-UP*

A sorption balance was used to measure the moisture storage capacity in the hygroscopic range. This balance enables automatic and relatively quick measure-

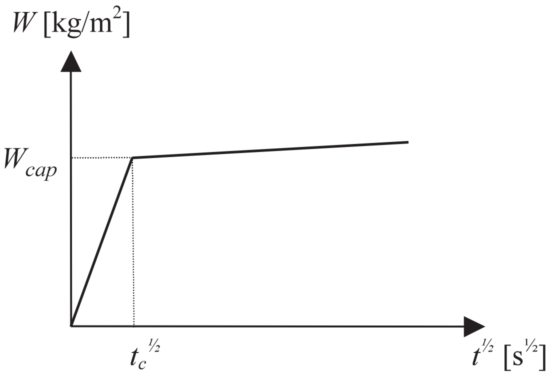

***Figure 1.*** *Capillary water absorption test used for determination of the sorption coefficient.*

ment of absorption and desorption of water vapor for small samples. Changes both in temperature and relative humidity around a sample can be programmed separately. A representative sample of the material to be tested is placed in a sample holder in the microbalance (see Figure 2). Moisture uptake in the sample is measured while it is exposed to airflow with a certain relative humidity, which is step-

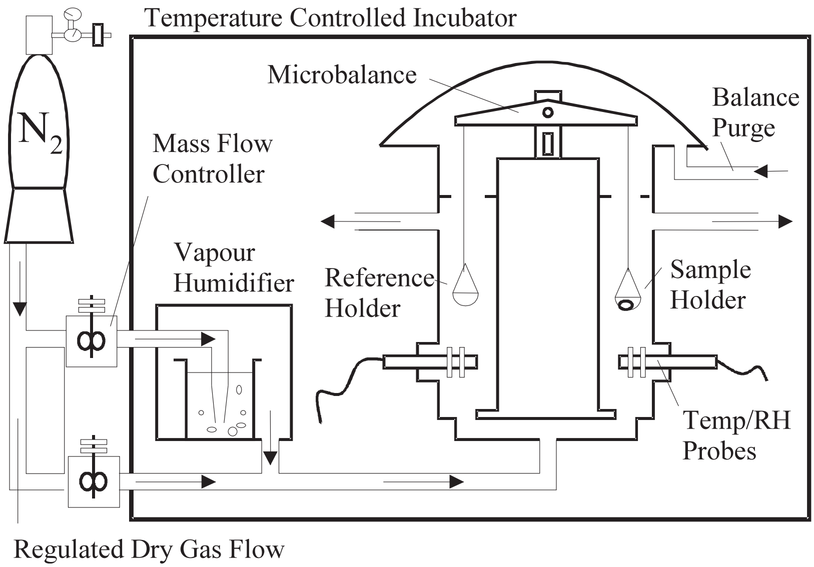

***Figure 2.*** *Schematic sketch of the dynamic vapor sorption instrument (DVS). Dry and saturated air are mixed in desired proportions using flow regulators. The sample, placed on a (symmetric) microbalance, is exposed to a continuous flow of air with a predetermined and constant relative humidity.*

wise changed by mixing dry and saturated air in desired proportions using mass flow regulators. The mass flow rate passing the sample is typically 0.001 m/s. Even though a specific relative humidity can be obtained by mixing dry and saturated air, humidity probes are situated just below the sample and reference holders to give independent verification of the performance of the system. The accuracy of the humidity probes is approximately ±0.4%.

The sorption balance measures changes in sample mass that are lower than 1 part in 10 million. The balance is therefore ideally suited for measuring vapor sorption. In order to avoid induced effects from vapor being adsorbed on the sample holder, a symmetric microbalance system is used (see Figure 2). The complete instrument is housed in a temperature-controlled incubator.

A slow, steady flow of mixed dry and saturated vapor gas passing the relatively small sample ensures that the relative humidity very near the sample surface and in the air surrounding the sample holder will be almost the same. The flow rate of the moist air is rather low, approximately 1 mm/s. This air flow helps to eliminate surface resistance to moisture leaving or entering the sample, which in turn results in equilibrium being reached faster. Furthermore, diffusion within the sample can be reduced by using very small, powdered samples, while still obtaining very accurate values for the mass changes of the sample.

The moisture storage capacity can be obtained by, for example, letting the system increase the relative humidity surrounding the sample in specified steps. The criterion for proceeding to a higher relative humidity is, typically, a prescribed value of the change in mass, which should be close to zero.

This method of measuring sorption has the disadvantage that composite materials with a representative length scale larger than the sample holder and representative samples exceeding the maximum allowed weight cannot be tested. In such cases, a representative volume of the sample can be grained and a small portion of the grained material can be used.

## *MEASUREMENTS*

The samples used for the sorption balance measurement were selected from a representative quantity of the material tested. Specimens of approximately 50 g were crushed using a mortar, and samples of 50–150 mg of this powder were randomly collected. The largest granule in the samples was approximately 0.1 mm.

Thereafter each sample was placed in the sample holder in the sorption balance (see Figure 2) and exposed to air of 0% relative humidity until the weight change was less than 0.0001% of initial weight per minute. The mass registered at this point was assumed to be the dry weight. Once the dry weight had been determined, the actual measurement started with the first and lowest relative humidity, followed by increasing relative humidity. Thus, the moisture storage capacity was reached by absorption. The sorption balance was programmed to increase the relative humidity in ten steps, from 9.5, 19, 28.5, 38, 47.5, 57, 66.5, 76, 85.5, to 95%.

The criterion of equilibrium was the same as when determining the dry weight, that is, a weight change of less than 0.0001% of initial weight per minute.

A desorption isotherm was also measured for the cement mortar. This measurement started with a water-saturated sample. In total 15 desorption steps were performed, ranging from 92% to 0% relative humidity.

After each measurement run the balance was calibrated using saturated salt solutions. The precision of the balance turned out to be ±0.7% relative humidity. All measurements performed with the sorption balance were carried out at 25°C.

## Determination of the Moisture Storage Capacity in the Superhygroscopic Range with Pressure Plate and Pressure Membrane Extractors

### *LABORATORY SET-UP*

The moisture storage capacity in the superhygroscopic range was measured by using overpressure to force water out of saturated specimens. Three different pressure vessels mounted with pressure plates or pressure membranes were used to obtain this overpressure. The pressure plates are made of a ceramic material and the pressure membrane is made of cellulose. One side of the ceramic plate/cellulose membrane on which the specimens are placed is exposed to an overpressure that can be adjusted, while the other side of the plate is always at atmospheric pressure. This arrangement results in a pressure difference over the ceramic plate/cellulose membrane and the specimen (see Figure 3).

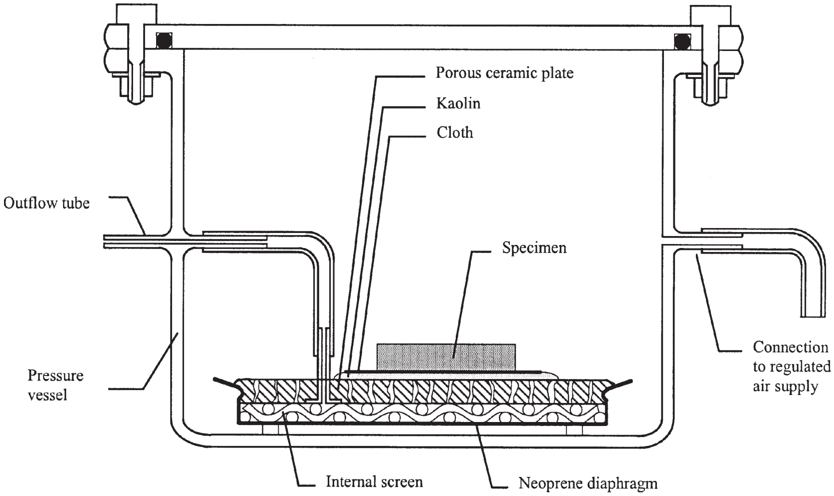

***Figure 3.*** *A sketch of a ceramic pressure plate and a specimen mounted in a pressure vessel. Excess water in the specimen is forced out of the specimen by overpressure. The internal screen prevents the neoprene diaphragm from clogging the underside of the ceramic plate when pressure is applied.*

In order to withstand the applied overpressure, the porous ceramic plate/cellulose membrane is saturated with water. Capillary forces in the pore system of the ceramic plate/cellulose membrane are then able to stand up to the maximum dimensioned pressure difference applied over the ceramic plate/cellulose membrane. Since the pores are saturated with water, they allow water but not air to pass through. The maximum applied pressure that the ceramic plate/cellulose membrane can withstand before air can pass through the pores is determined by the radius of the pores, $r_0$ (see Figure 4). It is advantageous to use plates with pores that are as large as possible since the test can then be carried out faster. The ceramic plates can stand pressures up to 15 bar and the cellulose membrane that is used for pressures above 15 bar is capable of withstanding pressures up to 100 bar.

A high-quality manifold pressure regulator controls the applied overpressure supplied by high-pressure nitrogen or air in tanks. The lowest possible pressure set-point for the equipment in use is approximately 0.001 MPa.

The equipment and the technique used for measuring retention curves originate from soil physics. The porous plate technique was first reported in Reference [12]. In order to use the equipment on solid materials, saturated kaolin clay is generally used to bond the specimen to the ceramic plate and to ensure good hydraulic contact between the specimen and the ceramic plate (see, e.g., Reference [6]). A cloth is placed between the kaolin and the ceramic plate to prevent the kaolin from penetrating the specimen (see Figure 3). Kaolin clay is never used on the saturated cellulose membrane since this membrane is soft and hydraulic contact can be achieved without using kaolin clay.

## *MEASUREMENTS*

The number of specimens used in the determination of the retention curves were 3 for the Gotland sandstone, 7 for the autoclaved, aerated concrete, 8 for the cement mortar, 7 for the cement-lime mortar, 10 for the lime silica brick, and 6 for each of the two other bricks tested. The sandstone specimens were approximately

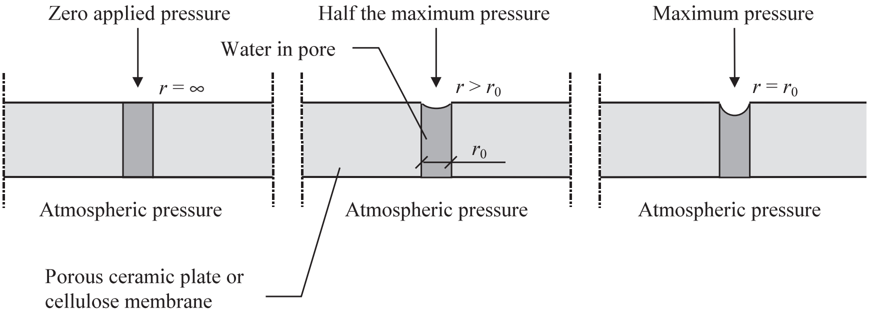

***Figure 4.*** *The function of the ceramic plate/cellulose membrane.*

25 mm in height, and the other specimens were approximately 10 mm in height. Except for the test performed on the sandstone, all measurements were carried out in an air-conditioned room at 20°C ± 1°C. The temperature was not registered during the measurement on the sandstone, but the experiment was performed at normal room temperature (i.e., approximately 21°C).

Before testing the materials, the specimens must be water saturated. Two different methods of saturating the specimens were used. The sandstone was capillary saturated by letting it suck water for approximately 24 hours; the other materials were saturated by vacuum using the procedure described in Reference [11]. Both methods of saturating specimens have been advocated in the literature. For example, in References [13] and [14] capillary saturation is used, and in the Nordtest standard NT BUILD 481 [6], vacuum saturation is prescribed.

Three different ceramic plates with different pore systems (pore diameter) were used. They were dimensioned to stand up to 1, 3 and 15 bar overpressure. Once the ceramic plate/cellulose membrane and the specimens had been mounted in the vessel, the first, and lowest, pressure level was applied. Overpressure then forced excess water out of the specimen, through the cloth, kaolin clay, and ceramic plate, and out of the vessel through the outflow tube (see Figure 3). The excess water was collected in a burette, and equilibrium was said to be achieved when the water outflow was less than 0.05 cm$^3$ in 48 h. At equilibrium, the mass of the specimens (i.e., the water content) was determined. Then, the specimens were remounted in the vessel and the next, slightly higher, pressure was applied. Since the test procedure starts with saturated specimens, equilibrium is reached through desorption.

## RESULTS

The porosity, density, and sorption coefficients of the materials are shown in Table 1. The measured moisture fixation is represented with the suction as storage potential. That is, the relative humidity measured with the sorption balance is re-

***Table 1. Porosity, density, and sorption coefficients for air-dried specimens.***

| Material | Porosity (%) | Density (kg/m$^2$) | Sorption Coefficient [kg/(m$^2$ s$^{½}$)] |
|---|---|---|---|
| Gotland sandstone | 23 | 2059 | 0.28 |
| Autoclaved aerated concrete | 79 | 594 | 0.098 |
| Cement mortar | 22 | 2053 | 0.015 |
| Cement-lime mortar CL 50/50/650 | 30 | 1853 | 0.091 |
| Brick 1, Kanik Antik | 26 | 1978 | 0.35 |
| Brick 2, Kanik Gul (hard burned) | 33 | 1863 | 0.13 |
| Lime silica brick | 28 | 1894 | 0.08 |

calculated as the corresponding suction using Equation (3). When using pressure plate extractors, the suction is measured directly. The moisture content of the material is represented by the moisture content mass by mass. It is also possible to calculate the pore size distribution from the suction using Equation (6); however, these calculations are not presented in this paper. The motive for using suction is that it provides higher resolution at high moisture levels. Each dot in the water retention curves presented corresponds to the mean value of the moisture content of several specimens.

Figure 5 shows the water retention curve for Gotland sandstone. The measurement with the pressure plate extractor started with capillary saturated specimens, corresponding to a moisture content of approximately 0.078. The highest measured value in Figure 5 is approximately 0.091; that is, the stone actually absorbed water during the experiment. The measured retention curves for the other materials appear in Figures 6–11. Figure 6 shows the retention curve of autoclaved, aerated concrete. The highest moisture content is 0.67, which corresponds to a degree of vacuum saturation of 0.52 (i.e., roughly half the moisture content at saturation). This reflects the pore size distribution of autoclaved, aerated concrete with a large proportion of pores emptied at pressures far below 0.01 MPa, which is the lowest possible pressure set-point with the equipment used.

In References [14] and [15], measurements of the moisture storage capacity of Gotland sandstone are presented. These measurements were performed in boxes with different saturated salt solutions. The measurements presented in Ref-

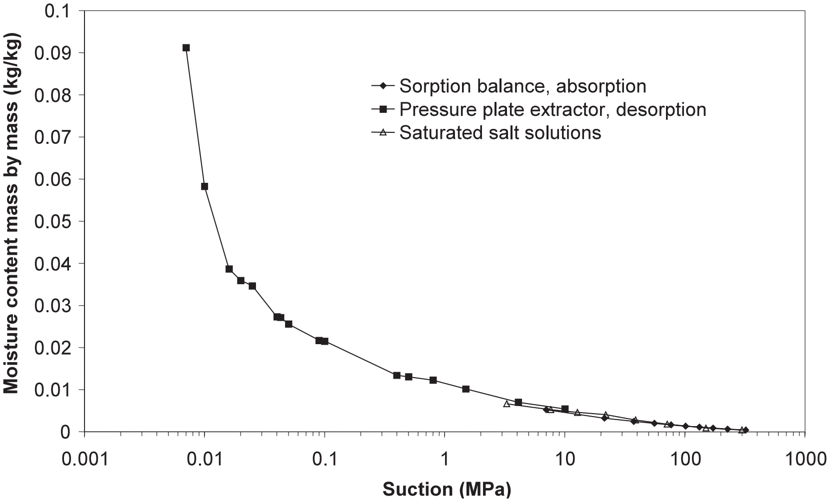

***Figure 5.*** *Retention curve for Gotland sandstone. The results obtained with saturated salt solutions originate from Reference [14].*

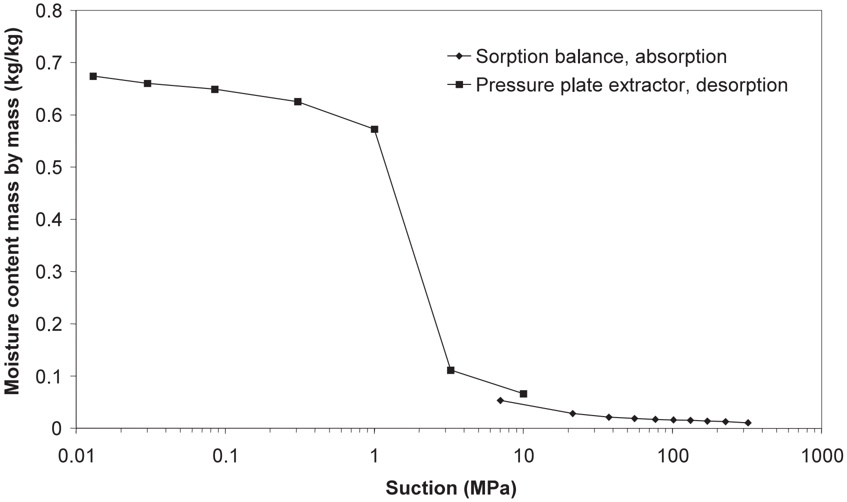

*Figure 6.* Retention curve for autoclaved aerated concrete.

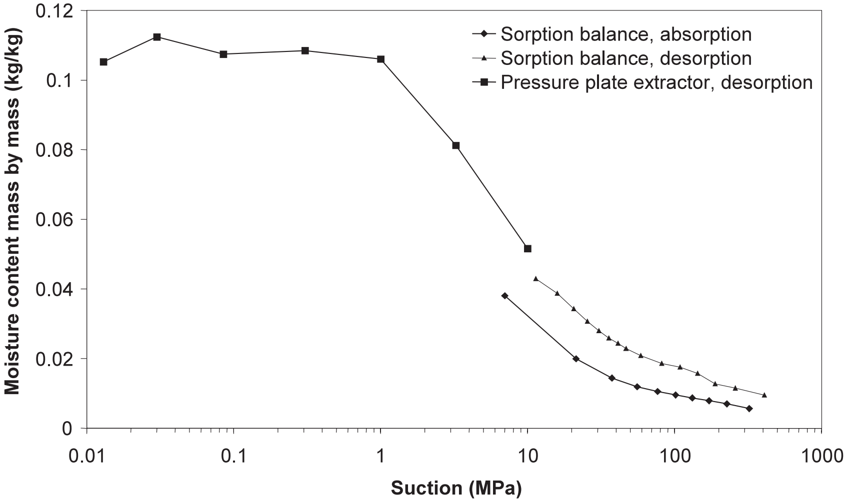

*Figure 7.* Retention curve for cement mortar.

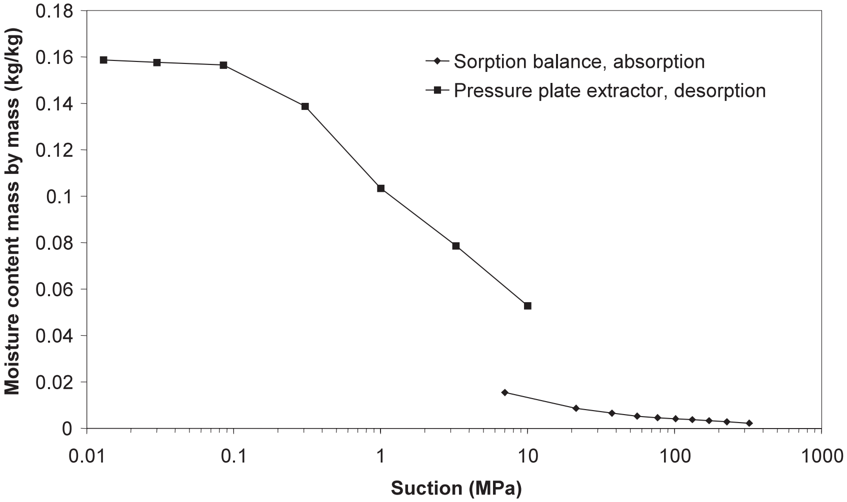

***Figure 8.*** *Retention curve for cement-lime mortar CL 50/50/650.*

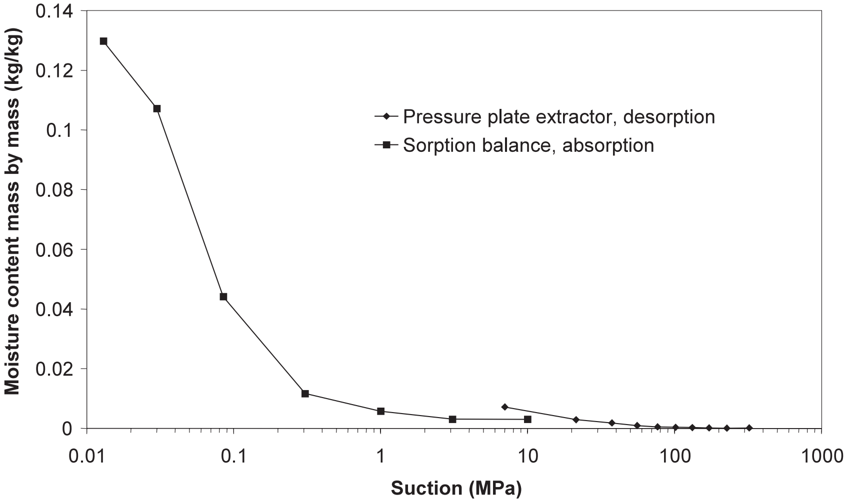

***Figure 9.*** *Retention curves for Brick 1, "Kantik Antik."*

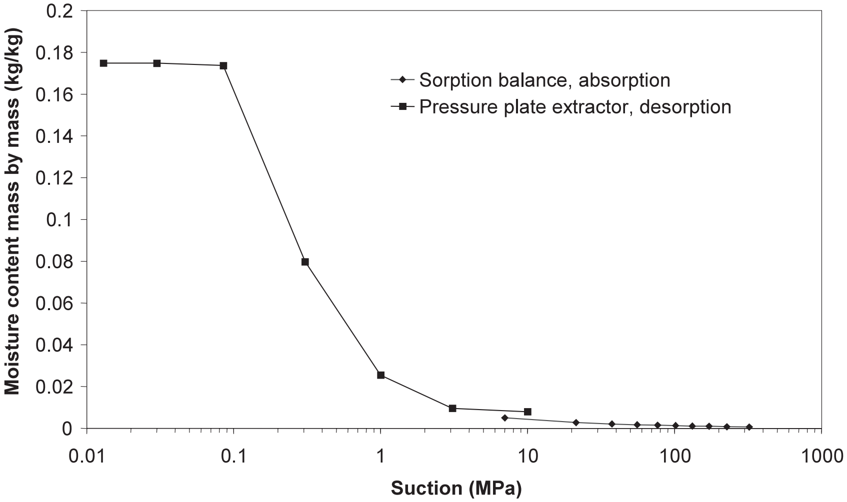

***Figure 10.*** *Retention curve for Brick 2, "Kantik Gul."*

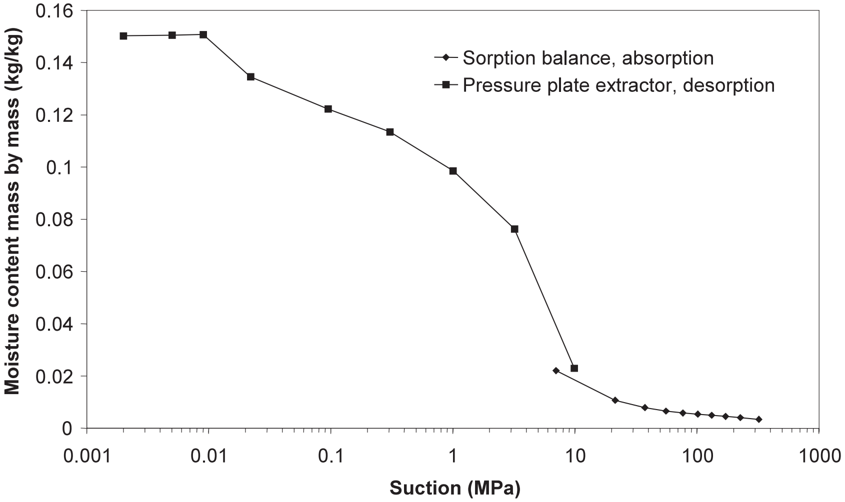

***Figure 11.*** *Retention curve for the lime silica brick.*

erence [14] are also shown in Figure 5. Neither in References [14] nor [15] was any hysteresis measured, i.e., the absorption and desorption curves measured in climate boxes were uniform.

In Figures 5–11, moisture storage capacities are shown with the suction used as the measure of moisture storage potential. This approach yields high resolution in the superhygroscopic range, but the resolution in the hygroscopic range is rather poor. Therefore, the moisture storage capacities in the hygroscopic range, measured with the sorption balance, are presented with the relative humidity used as the measure of moisture storage capacity in Figures 12 and 13. All isotherms except that for the cement mortar were measured through absorption. On the cement mortar, both absorption and desorption isotherms were measured (see Figure 12).

For Brick 1 "Kanik Antik" the absorbed amount of moisture was very low up to approximately 50% relative humidity which caused difficulties in measurement because the error of the sorption balance becomes proportionally higher. The registered moisture level at 9.5% relative humidity is higher than at 19%. This is attributed to an error due to inaccuracies in the measurement performed with the sorption balance.

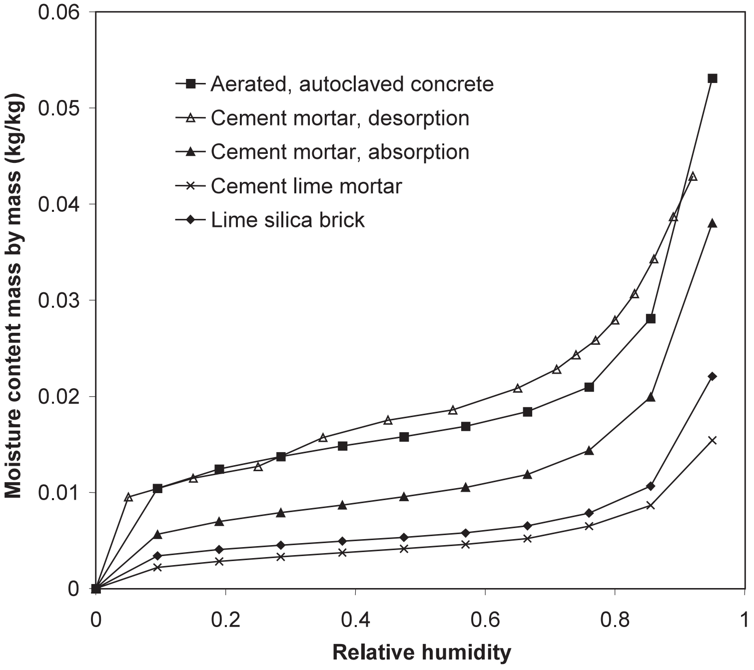

***Figure 12.*** *Absorption isotherms in the hygroscopic range for aerated autoclaved concrete, cement mortar (also desorption), cement-lime mortar and lime silica.*

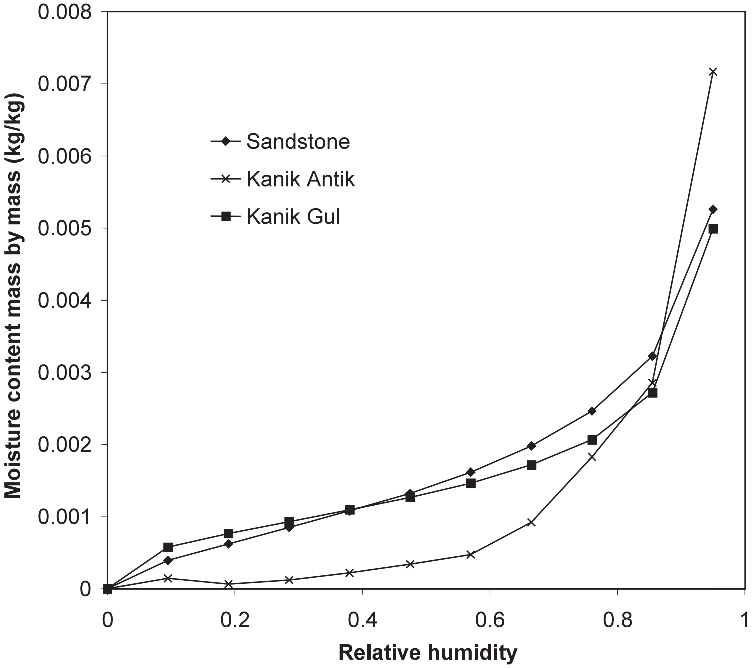

***Figure 13.*** *Absorption isotherms in the hygroscopic range for Gotland sandstone and the two tested bricks.*

## DISCUSSION AND CONCLUSIONS

The combination of a sorption balance and pressure extractor makes it possible to measure moisture storage capacity in both the hygroscopic and the super-hygroscopic range. The limitation of this combination is that moisture contents corresponding to suction lower than 0.001 MPa cannot be measured [i.e., water in pores with a pore radius larger than 0.15 mm according to Equation (6) cannot be detected]. However, very few building materials have pores larger than 0.15 mm. Thus, the combination of the two techniques is a powerful tool for determining the moisture storage capacity of building materials.

Apart from the cement mortar, all samples used with the sorption balance started out as dry samples. Hence, the moisture storage capacity was reached through absorption. Since the highest allowable moisture level with the sorption balance is approximately 95% relative humidity, the true desorption isotherm cannot be measured by lowering the relative humidity from this level after equilibrium is reached at 95%. The "desorption" isotherm measured in this way will actually be a scanning curve from absorption to desorption. In order to measure desorption isotherms accurately, the measurement must start with a saturated sample. Once equilibrium at 0% relative humidity has been reached, it is possible to increase the vapor content and measure an absorption isotherm. Thus, measurements with the sorption balance should start with saturated samples so that equilibrium can be reached through both desorption and absorption during the same run. This was done for the cement mortar.

With the pressure plate and pressure membrane extractors used in this study, equilibrium can only be reached by desorption. With a small modification of the equipment, absorption retention curves also can be measured. Such curves have been measured by Penner [16]. The results presented in Figures 5–11 are therefore obtained through desorption in the superhygroscopic range and through absorption in the hygroscopic range. Due to hysteresis, the equilibrium levels reached through absorption should be lower than the equilibrium reached through desorption. This is the case for all materials tested except for Gotland sandstone and Brick 1. For the sandstone, the curves measured with the sorption balance (absorption) and with the pressure plate/membrane extractor (desorption) were identical, indicating that there is no hysteresis between absorption and desorption. This is probably the case since neither References [14] or [15], both of which measured moisture storage capacity using saturated salt solutions, identified any hysteresis. For Brick 1, the equilibrium reached through absorption is slightly higher, which is, of course, quite impossible. The error can probably be ascribed to inaccuracies in the measurement performed with the sorption balance because the ratio between the amount of moisture absorbed and the dry weight was very low on the brick in question.

The desorption isotherm measured with the sorption balance for the cement mortar matches the desorption curve measured with the pressure plate/membrane extractor, proving that the large gap between the equilibrium reached through desorption and absorption is due to hysteresis and not due to any error in the test. The difference between absorption and desorption was found to be higher for the cement-lime mortar than for the cement mortar. This implies that hysteresis is dominant even in the superhygroscopic range for cement mortar and cement-lime mortar. It is therefore of greatest importance that the equipment used in the superhygroscopic range be modified so that the absorption isotherm can also be measured.

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