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# Canadian Building Digest

Division of Building Research, National Research Council Canada

**CBD 130**

## Wetting and Drying of Porous Materials

*Originally published October 1970*

*P.J. Sereda and R.F. Feldman*

### Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Most porous materials change their volume with changes in moisture content. On wetting, plaster may expand and fall from the ceiling; on drying, wood may shrink and crack. Soils may swell and shrink due to seasonal change in water content. These and other effects of water on porous building materials have been described in [CBD 30](#) and [CBD 84](#). They are the result of physical changes brought about by changes in moisture content that may cause deterioration of a material and shorten its useful life.

The behaviour in service of porous building materials must be predictable, and prediction can be based only on prior experience with identical material in similar applications or on understanding of the processes that bring about changes. In modern building old materials are used in new ways and new materials are used without long-term experience. Prediction of performance must therefore be based on a basic understanding of material properties and environmental influences. This Digest will discuss the various processes by which a material is wetted or dried and the effect that water has on the material.

### Water Outside the Material

The environment can be a source of or reservoir for water in the pores or on the surface of a material and controls the conditions of its moisture content. ([CBD 120](#)) discusses the relation of design and environment in controlling moisture in the material. [CBD 112](#) discusses response of wood to cycles of high and low relative humidity in the atmosphere.) Water in the environment exists in three states: vapour in the air ([CBD 1](#), [CBD 57](#)), liquid as rain ([CBD 6](#), [CBD 42](#)) or groundwater ([CBD 82](#)), and solid as snow or ice. Of these, water as vapour in the surrounding air is the most readily available source ([CBD 23](#), [CBD 108](#)) and the most effective in distributing the water uniformly throughout a porous material.

Just as weather is changeable, so also the environment in which materials serve changes, having daily and seasonal cycles. The duration of the daily cycle is often too short to have an appreciable effect on materials of reasonable mass and the response is usually to the average daily condition. Rainfall is an exception since its occurrence is random. Even groundwater may be cyclic with the seasons and certainly with the amount and duration of rainfall.

## **Wetting and Drying of Surfaces**

As long as water in the three states is in the environment outside a material, it can be referred to as bulk water and its behaviour is predictable on the basis of the normal properties of water. When it comes into contact with the surface of a material, however, its behaviour is no longer predictable on the basis of its bulk properties. A drop of water placed on the surface of paraffin remains as a hemisphere, leaving the surrounding surface totally dry in contrast with the behaviour of a similar drop of water placed on very clean glass. Here it spreads, wetting a large area and assuming the nature of a film.

An even more dramatic illustration may be made by placing a drop of water on the surface of a porous brick; the water not only spreads on the surface but also enters the material, disappearing into the pores and leaving only a damp spot at the surface. If the same brick had been pre-treated with a non-wetting agent such as a silicone, the drop would remain on the surface as with paraffin. The different behaviour of water in the two environments demonstrates the mutual influence exerted by the water and the surface of the material. It also demonstrates that this interaction occurs between the water adjacent to the surface and the first surface layer of molecules (which may be a contamination material) and not the bulk of the material.

The first layer of atoms at any surface is at an energy state different from that of the underlying atoms within the material owing to an imbalance of forces. This results in what is described as interfacial energy or surface energy. In liquids it is called surface tension. The surface energy, as would be expected, varies with the nature of the surface as defined by the particular atoms at the surface and their interactions with neighbouring atoms.

Surfaces that are wetted by water have an attraction for water molecules. This results in a process of adsorption whereby a definite amount of water will be held at equilibrium with the relative humidity of the environment. Where the material has a very low surface area (non-porous material) the total amount of water held by the material will be insignificant. Where the material is porous, however, and the total surface area is large, the amount of water held will also be large as is discussed in a later section of this Digest.

### **Dry Material in Contact with Sources of Water**

#### *Non-Porous Material*

When a non-porous material such as metal cladding comes in contact with water as vapour, liquid, or solid, it will quickly come into equilibrium with the environment because the amount of water that such a material can hold is small. If, in addition, the mass of the material is small, so that its surface temperature close to that of the atmosphere, the surface moisture condition will cycle closely with the moisture condition in the environment. Surface films of water will be very thin and invisible until the relative humidity at the surface is near saturation (100 per cent). Processes such as corrosion of metals begin when the film of water is equivalent to about 85 per cent RH. Other processes such as staining and discoloration will begin when saturation has been reached or water as liquid or condensate has been deposited in heavy films or droplets. At this stage coalescence of the drops may begin and streaming or irregular drainage of the excess water can be observed. The amount of water that can be held on any surface is dependent on orientation (horizontal or vertical) and on the chemical and physical nature of the material.

On wettable surfaces invisible films of water will form on exposure to humidity in excess of 50 per cent RH, but the total water held even at 100 per cent will be small unless the texture is rough. Surfaces that are not wetted by water will remain virtually dry at any condition of relative humidity unless that surface is held at a temperature below the dew-point of the environment or liquid water is brought into contact with it. When water is deposited on such surfaces, very large drops will form.

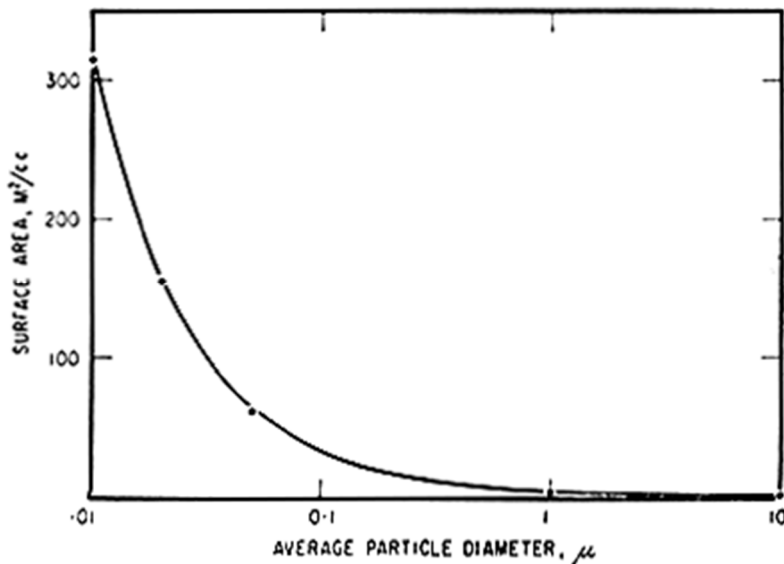
From the standpoint of wettability the surfaces of most practical materials fall between the two extremes. A completely wettable material may become contaminated in service with organic

deposits that render it partially non-wetable by water. Similarly, a completely non-wetable material like a protective coating may become partly wettable in time because of inorganic contaminants such as salts, and because of surface deterioration.

#### *Porous Material*

Some materials having coarse, interconnected pores and no internal micropores (certain sands or gravels) will behave the same as non-porous materials in contact with various sources of water and for the same reasons. The significant difference between this class of materials and those classed as non-porous is that liquid water and vapour and air and other gases can pass readily through the large spaces between the particles.

Most porous building materials -- wood, concrete, plaster, stone, brick, tile -- have fine, interconnected pores and thus have a large surface area, as discussed in **CBD 127**. If one considers spherical particles as microunits cemented together, the relation of particle size and total surface area is given in Figure 1. From this it is evident that materials such as hydrated cement in concrete have a surface area about one hundred times larger than that of plaster or brick simply because of the difference in particle (microunit) size. Although surface area is an important parameter in predicting the effects of interaction with water, it is not possible to list specific values for common materials because these differ greatly from one sample to another and values for many materials are not yet available. A material like wood has different values for different species. It is revealing, however, to have approximate values for comparison, For example, most rocks have a surface area below  $1 \text{ m}^2/\text{g}$ , brick, tile and plaster have a surface area of  $1$  to  $10 \text{ m}^2/\text{g}$ , whereas hydrated cement has a surface area of  $10$  to  $100 \text{ m}^2/\text{g}$ .



*Figure 1. Relation between particle size and surface area per unit volume of material.*

To assist in the prediction of the behaviour of porous materials under different conditions of moisture, both liquid and vapour, it is necessary to know values of surface area, pore-size distribution, and total porosity. Brick and concrete may have the same moisture content at saturation but, because of the differences in surface area, at 50 per cent RH brick may have  $\frac{1}{2}$  per cent and concrete 5 per cent moisture. The sorption isotherms (Figure 2) for common porous materials indicate the relation of moisture content to relative humidity. This depends on the nature of the material, the total surface area, and pore sizes and total pore space.

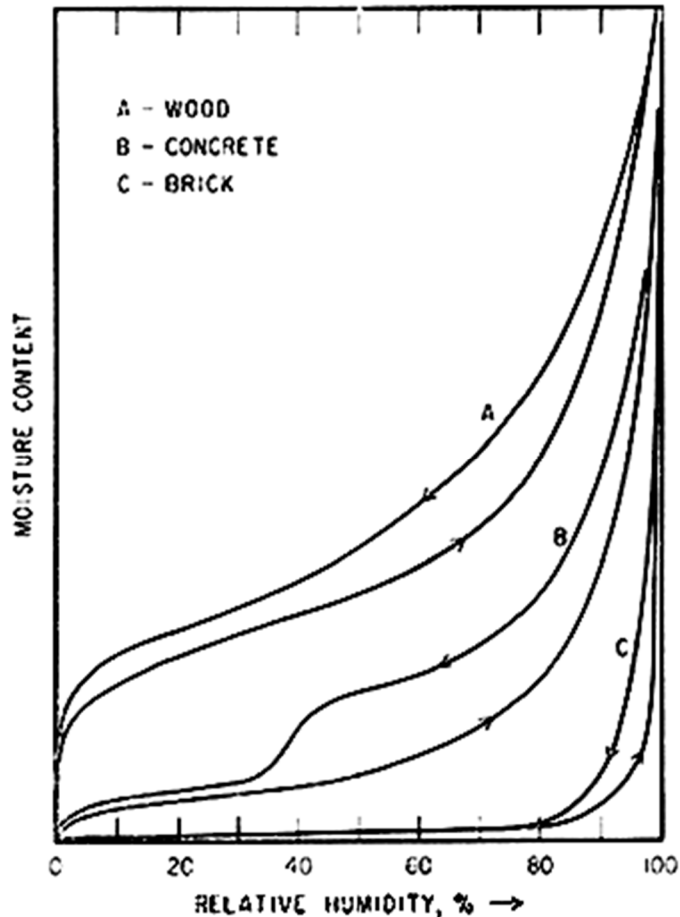


Figure 2. Sorption isotherms

It is to be noted that these relations are for the equilibrium condition and where a dry material is exposed to increasing levels of constant relative humidity until saturation (producing the absorption part of the curves), followed by exposure to decreasing levels of constant relative humidity (producing the desorption end of the curves). It should also be noted that the equilibrium drying (desorption) curve, as shown in the isotherm, does not coincide with the wetting (adsorption) curve, especially at high humidity. The separation is referred to as hysteresis. It is for this reason that different moisture contents can be obtained for the same RH condition, depending on the history of the sample.

In service, materials seldom if ever are at equilibrium with conditions in the environment, which are continuously changing. Brick with an average pore size greater than  $1\mu$  will, however, follow the condition in the environment much closer than concrete, in which the hydrated cement has an average pore size below  $0.01\mu$ .

In considering the time required for a material to reach equilibrium with a condition of relative humidity in the environment, it is necessary to include the dimensions of the sample. Obviously, a very thin slice of porous material is almost equivalent to a non-porous surface, and will reach equilibrium quickly. The practical dimension of 4 to 6 inches, however, represents a maximum path length for the water of 10 to 15 inches, or about 2.5 times the nominal dimension because of the tortuous path. (This value changes for different materials.) For diffusion of vapour into the material the rate is proportional to the vapour pressure difference and the permeance (CBD 57). If the temperature of the material is the same as that of the environment, moisture content will approach uniform distribution. When the temperature is not the same, there is a possibility that the temperature of a section of the material will be at or below the dew-point of the air-water vapour mixture and that condensation will occur,

resulting in saturation of one portion of the pores. Large gradients of moisture content can be realized in this way. This is one mechanism by which water can be deposited at the paint-wood interface of a painted board cladding on a building. Blister boxes for paint testing employ this mechanism.

When dry porous materials (having wettable surfaces) come in contact with liquid water, the wetting process that follows involves capillary conduction, where suction acts as the driving force, and is quite different from water vapour diffusion. Wetting by liquid water proceeds as a front involving a very steep gradient of moisture content. The advance of this front into the porous material is characteristic of the material (each material having its rate constant) and decreases with the square of the distance travelled. It will take approximately four times as long to pass through a sample 2 inches thick as it will a sample 1 inch thick, both of identical material. When the wetting front passes through the material, thus saturating it, the flow ceases unless a head or pressure difference is applied on the source of water. The flow that follows through the saturated material involves a different process, being controlled by the permeability and the hydraulic pressure difference. Wetting by contact with liquid water produces very large moisture content gradients, in contrast with wetting by vapour unless the latter also involves a temperature gradient.

A porous material like brick that has been treated with a non-wetting agent such as silicone will not transmit water by capillary conduction and will not wet on contact with liquid water. There is, however, a common misconception about the ability to saturate such a porous material. Water can be pushed in by pressure differences developed by wind. In addition, water vapour will diffuse into such a material and can condense if the temperature in the material is lowered to the dew-point.

Water in the solid state, ice or snow, can control the relative humidity of the surrounding air and in this way influence the moisture content of a material. At low temperatures and corresponding low vapour pressures the rate of transfer of water will be much slower than if liquid water were the source. If the material is at the same temperature as the ice or snow and there is no air circulation, the moisture content will approach saturation because the relative humidity of such an environment is near 100 per cent. If the material or the surrounding air is at a temperature above that of ice or snow, however, then the relative humidity will be decreased and final moisture content of the material will be below saturation. Under these conditions a wet sample would experience desiccation.

### **Wet Material -- Drying**

Saturation of a material is defined as the condition where all pores are completely filled with water. This state is seldom realized in practice and special techniques such as vacuum-saturation are required to ensure it. Even immersion of a material in water traps air in the pores, thus preventing saturation. Materials such as concrete or plaster that begin as a solid-water mix are in the saturated state when first made. Such materials are in a special situation of first experiencing a drying process before reaching the conditions of service. This may result in irreversible effects such as shrinkage and cracking (**CBD 119**).

The drying process involves two distinct periods: the constant rate period where free water is brought to the surface from the coarse pores by capillarity and is evaporated to the surrounding air; and the falling rate period when surface and vapour diffusion are responsible for removal of adsorbed water from the fine pores. With porous material treated with a non-wetting agent, the mechanism for bringing free water to the surface by capillarity is interrupted and consequently the rate of drying is considerably reduced.

In drying as in wetting materials of fine porosity, there exists a sharp gradient between the wet and the dry portion of the material. This can be avoided only by decreasing the relative humidity conditions by small increments and allowing a long time for equilibration. In materials of coarse porosity this gradient is decreased markedly, as is the time required for removing most of the water. Brick in a wall comes very close to saturation when exposed to driving rain lasting some hours, but similarly it will lose most of this water in about one day of drying

weather. With concrete, however, months and sometimes years are required to dry thick sections to a moisture content corresponding to the average relative humidity in the atmosphere. Thus bricks can respond to daily changes in moisture conditions, whereas only the surface layers of concrete are affected by changes of short duration.

### **Summary**

The performance of building materials depends to a large measure upon the conditions of moisture to which they are subjected, involving both the levels of moisture content and their cyclic changes. It is in the interest of the designer and specifier to be aware of the factors involved and to have an understanding of the processes if optimum performance of materials is to be achieved.