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Determination of the water retention curve from drying experiments using infrared thermography: A preliminary study

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ABSTRACT

A method is proposed for experimental determination of the water retention curve from drying tests performed on capillary active materials. Non-destructive techniques (gravimetric analysis, infrared thermography) are employed for measuring water content, drying rate and surface temperature during time for a set of material samples. The surface relative humidity is calculated from the measured data through analytical procedure. Hence, assuming uniform water content distribution inside the samples, which applies if the mass transfer Biot number is small enough, the relation between relative humidity and water content is derived. This relation represents the water retention curve for the considered transient desorption behavior and, as shown in previous studies, it may deviate from the trend measured through steady state experiments.

The proposed method differs substantially from other ones commonly employed to the same aim. It is useful for investigation of the so called dynamic effects, recently observed by other authors in the hygrothermal behavior of construction materials. For a first test, calcium silicate specimens are employed and the results are compared with those reported in the literature. An error propagation analysis is also included.

1. Introduction

Deep knowledge of heat, vapor and liquid water transfer in construction materials is a prerequisite for the proper design of building components. This is particularly relevant in cases where an existing building is refurbished by applying internal insulation [1]. For this reason, a great effort in both numerical modeling and experimental research has been recently made on this topic by numerous authors [2–9]. The purpose of this work is to extend the present knowledge by investigating the drying behavior of calcium silicate, the importance of which as capillary active thermal insulation material has been already shown in the literature [10,11].

A new method is proposed for experimental determination of the water retention curve in both the hygroscopic and super-hygroscopic ranges, based on non-destructive measurements and analytical procedure. The proposed method is less time consuming and differs in a substantial way from the other ones used for the same purpose.

2. State of the art

The water retention curve describes the capability of a porous material to retain water inside its air cavities and represents an important input for transient modeling of heat and moisture transfer. It can be expressed as a relation between the local water content and the relative humidity or, alternatively, the capillary pressure (Fig. 1).

Commonly, for modeling the behavior of building materials, local equilibrium between liquid and vapor phase is assumed. In other words, a one-to-one correspondence between local water content and relative humidity is defined at every time step, independently of the process dynamic. According to this assumption, the water retention curve can be obtained through experiments performed at steady state conditions. Commonly employed techniques are the desiccator method [12,13] (for measurements in the hygroscopic range i.e. relative humidity below approximately 95%)

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Nomenclature

A	specimen surface $[m^2]$
Bi	Biot number $[-]$
c	heat capacity $[J/(kg\,°C)]$
d	specimen thickness $[m]$
D	diffusivity $[m^2/s]$
L	characteristic length $[m]$
Le	Lewis number $[-]$
m	mass $[kg]$
$\dot{m}$	drying rate $[kg/s]$
Nu	Nusselt number $[-]$
p	pressure $[Pa]$
Pr	Prandtl number $[-]$
Re	Reynolds number $[-]$
R	gas constant $[J/(kg\,K)]$
s	standard deviation
T	absolute temperature $[K]$
t	time $[s]$
u	water content $[kg/m^3]$
v	air velocity $[m/s]$
V	specimen volume $[m^3]$
$x; y; z$	coordinates $[m]$
X	parameter Eq. B.5 $[Pa]$
α	heat transfer coefficient $[W/(m^2K)]$
β	mass transfer coefficient $[s/m]$
θ	Celsius temperature [°C]
λ	thermal conductivity $[W/(m\,K)]$
ρ	density $[kg/m^3]$
φ	relative humidity $[-]$

Subscripts

a	air
c	capillary
dry	dry material
f	free saturation
lam	laminar
m	mass transfer
p	constant pressure
sat	saturation
s	surface
$turb$	turbulent
v	vapor
vol	volume
w	liquid water
∞	in the surrounding air

and the pressure plate test [3,13] (for characterization of the super-hygroscopic range).

By applying such steady-state methods, the hysteresis between ad- and desorption, widely studied in previous works (e.g. Ref. [12]), can be observed. However, transient procedures are required in order to investigate the influence of the process dynamic on the material behavior.

Even if the assumption of local equilibrium is common in hygrothermal modeling, recent studies pointed out that, in some cases, it may be quite inaccurate. In Ref. [14], the authors gave experimental evidence of this by carrying out drying, absorption and desorption tests and measuring both water content and relative humidity during time at different positions.

By comparing these results with those obtained at equilibrium conditions through standard techniques, a significant deviation was observed. The measuring equipment employed in that study included different types of sensors and a sophisticated experimental setup: the relative humidity was measured by means of psychrometers (above 96%) and capacitive sensors (below 98%) while the water content was determined through a X-ray projection.

In this study, we propose an alternative method based on non destructive measurements, i.e. infrared thermography and gravimetric analysis. These techniques have been already successfully applied for the assessment of the moisture content in porous building materials in previous works (e.g. Refs. [15–18]). In particular, in Ref. [16] surface temperature measurements are used in combination with gravimetric analysis to determine the transition water content between the super-hygroscopic and hygroscopic range during drying.

In a similar way, in this study the water content and the surface temperature of calcium silicate specimens are measured at different times. Considering that, at least during the early drying period, the water content and temperature inside the specimens are almost uniform, it is possible to determine the transient behavior of the relative humidity trough a mathematical procedure. Hence, the water retention curve can be obtained by linking the relative humidity to the water content.

3. Experimental setup

The experiment consists of drying material samples, previously

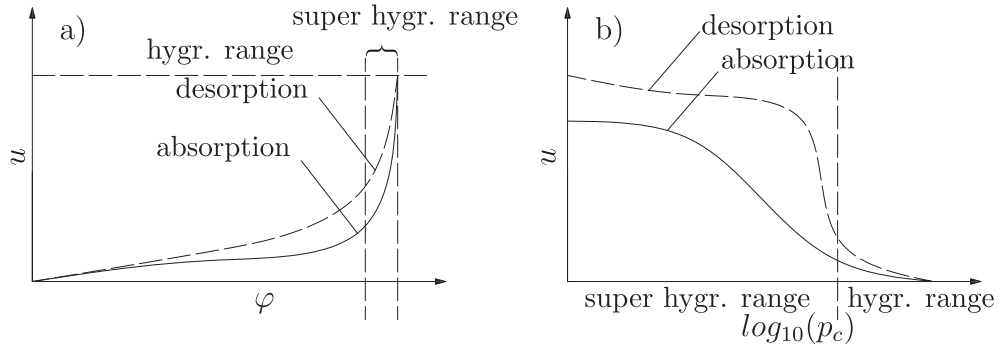

Fig. 1. Water retention curve determined through steady state measurements for absorption and desorption. a) water content versus relative humidity; b) water content versus logarithm of capillary pressure.