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Moisture estimation in building materials with a simple procedure

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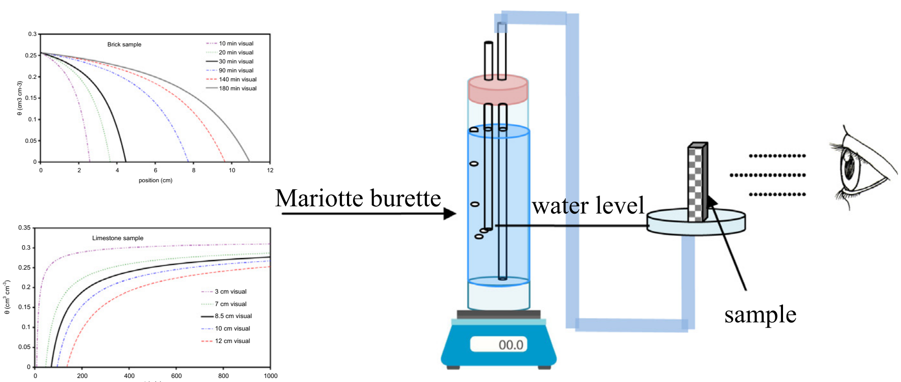
HIGHLIGHTS

- Simple experimental procedure using readily available measuring equipment.
- Transformed profile generation using optimization for any porous building material.
- Estimation of moisture profiles θ(t) and θ(x) in building materials.
- Accurate measurement of inlet water quantity using Mariotte Burette.

GRAPHICAL ABSTRACT

Method to estimate moisture profile propagation in porous building materials with a digital scale and visual inspection.



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ABSTRACT

A lot of research is carried out in water flow through soils, where soils are treated as porous media. Since many building materials can be also considered as porous media the same theories and methods can be applied. The aim of this research is to provide an easy laboratory method to estimate vertical moisture profiles in building materials. The method is based on measurements of porosity, accurate measurements of the sample dimensions. During the experimental procedure, visual inspection of the profile length θ(x) and measurements of inlet water as a function of time are monitored. From the previously obtained data, the transformed profile is generated by treating the whole process as an optimization problem. The method was applied to two different building materials namely limestone and brick and the results were verified through another experimental procedure using gamma ray (γ-ray) absorption. The results show that this method can be used to estimate transformed profile and consequently θ(x) and θ(t) profiles. It is heavily based on visual observations of the profile length utilizing few and inexpensive equipment with quite accurate results. Accuracy was better than 2.5% regarding sorptivity calculated from γ-ray produced λ(θ) profiles on one hand and by the proposed method on the other.

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1. Introduction

Knowledge of the moisture content in building materials is very important since moisture is responsible for frost damage, salt crystallization, mould growth and corrosion of reinforcement bars in concrete structures. It also causes degradation, due to freeze and thaw cycles, while it is responsible for cracks and spalling in concrete. A lot of research is carried out in measurements and prediction of moisture in building materials that are considered to behave as porous media. There are many methods to measure moisture in these types of media categorized as destructive and non destructive.

The destructive methods that were originally used required the sectioning of the sample and the volumetric measurement of the moisture content. Certainly more advantageous are the non-destructive methods since the sample remains intact and measurements can be repeated. The non-destructive methods are γ-ray method [25–28,18], microwave method [42], microfocus X-ray method and computerized tomography (CT) techniques [23,10,34,35,38,36,6,37,29], nuclear magnetic resonance (NMR) [12,13,1,41,45,31,4], positron emission tomography [15,11], electrical resistance or dielectric variation measurements [44,20,33,21,22,39,16], ground penetrating radar (GPR) or impulse radar [2,19,40,46].

All these methods have the disadvantage of using quite expensive laboratory equipment and also specific safety measures are required. Similar methods have been utilized to measure and predict moisture content in soil samples that are also treated and behave as porous media. According to Childs [7], Philip [32], Hillel [14], Pel et al. [30], Kaufmann et al. [17] vertical infiltration phenomena in soil or porous media with very small hydraulic conductivity, can be described sufficiently, using horizontal absorption equations. This is based on the assumption that on such media, the capillary forces are greater than the forces of gravity and therefore gravity can be neglected.

In this article a method for moisture profile propagation during vertical infiltration in porous construction materials such as limestone and brick is examined. The method is tested and verified for these materials. Previously, the same method was tested and verified during horizontal absorption in soil samples [8,9]. The proposed method can estimate moisture profiles propagation in building materials with few and inexpensive laboratory equipment. It is based on visual moisture profile observations from the discoloration of the sample, accurate measurements of absorbed inlet water versus time and knowledge of the saturated moisture content of the material under test. The whole process is treated as an optimization process in order to extract the transformed moisture profile. The results of this simple method were verified by repeating the experiment and measuring the profiles using γ-ray equipment.

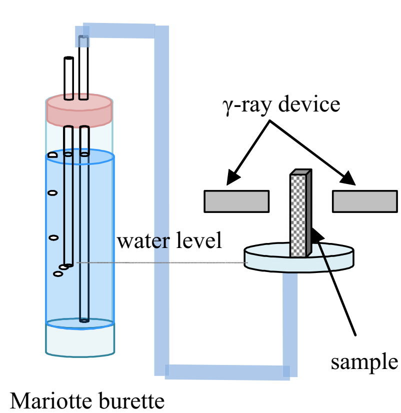

Fig. 1. Experimental set up.

2. Theory

The one-dimensional horizontal movement of water in unsaturated soils or materials can be described by:

$$\frac{\partial\theta}{\partial\theta} = \frac{\partial}{\partial x}\left[D(\theta_x)\frac{\partial\theta}{\partial x}\right] \qquad 0 < x < \infty \tag{1}$$

where θ is the moisture content (L^3L^{-3}), D is the diffusion coefficient (L^2T^{-1}), x is the position (L), of the moisture profile at a particular time and t (T) is the time.

Eq. (1) implies that the Darcy law is valid for unsaturated flow, whereas it is assumed that a unique relationship exists between the pressure head and the water content [24]. The initial and boundary conditions of the equation are:

$$\begin{aligned} &\theta(x,t) = \theta_i,\ x \geqslant 0,\ t = 0 \\ &\theta(x,t) = \theta_0,\ x = 0,\ t > 0 \\ &\theta(x,t) = \theta_i,\ x \to \infty,\ t > 0 \end{aligned} \tag{2}$$

where θ_i is initial moisture and θ_0 is final moisture which may reach the upper limit of saturated moisture content θ_s.

Using Boltzmann transformation $\lambda = xt^{-1/2}$, which implies that moisture content is a single value of λ. Moisture profiles are transformed from θ(t) into θ(λ) and Eq. (1) is converted into an ordinary differential equation:

$$-\frac{1}{2}\lambda\frac{d\theta}{d\lambda} = \frac{d}{d\lambda}\left[D(\theta_x)\frac{d\theta}{d\lambda}\right] \tag{3}$$

with the following boundary conditions:

$$\begin{aligned} &\theta x = \theta_i \quad \lambda \to \infty \quad t > 0 \\ &\theta x = \theta_0 \quad \lambda = 0 \quad t = 0 \end{aligned} \tag{4}$$

Integrating Eq. (3) from θi to θx, then the equation of the diffusion coefficient is obtained as a function of moisture θ:

$$D(\theta_x) = -\frac{1}{2}\frac{1}{\left(\frac{d\theta}{d\lambda}\right)_{\theta_x}}\int_{\theta_i}^{\theta_x}\lambda d\theta \tag{5}$$

According to Philip [32], sorptivity (S) is given as:

$$S = \int_{\theta_i}^{\theta_0}\lambda \quad d\theta \tag{6}$$

The cumulative infiltration (I) to the wetting front can be expressed as:

$$I = \int_{\theta_i}^{\theta_0} x \quad d\theta \tag{7}$$

Thus, the cumulative infiltration Eq. (7), which is the total volume of water (M_{water}) entering per unit area (Area), can be expressed by:

Table 1
Values obtained through the visual experimental process.

t (min)	Xprofile (cm)	λ (cm $min^{-0.5}$)	S (cm $min^{-0.5}$)
Limestone sample			
28.74	6	1.1192	
87.99	9	0.9595	
98.91	10	1.0055	
Average		1.028	0.2048
Standard Deviation		0.0822	
Brick sample			
37.4	6.7	1.0956	
83.65	8	0.8747	
121.67	9	0.8159	
Average		0.9287	0.1512
Standard Deviation		0.1474	