DETERMINATION OF SATURATED WATER CONDUCTIVITY COEFFICIENT IN BUILDING MATERIALS

Zbigniew Suchorab, Ewa Zarzeka-Raczkowska

Lublin University of Technology, Faculty of Environmental Engineering
Nadbystrzycka St. 40B, 20-618 Lublin, Poland
e-mail: Z.Suchorab@wis.pol.lublin.pl

Summary:
Capillary water uptake is a serious phenomenon influencing the functioning of old and newly raised buildings, thus modeling of this process is very important for prediction of the behavior of building objects. Among many models of water transport in building barriers Richards model of unsaturated water flow can be distinguished. This model of water transport in porous materials can be seriously applied for capillary uptake simulations and can be useful to predict behavior of the walls which are prone to groundwater influence. One of the most important empirical parameters which are applied in the above mentioned model is hydraulic conductivity coefficient *k*, which, depending on type of water flow can be expressed in saturated state (saturated water conductivity coefficient k_s) and water conductivity in relation to moisture for unsaturated water transport model.

This article presents basic information about water transport models in saturated and unsaturated states that can be applied for prediction of capillary rise phenomenon in building barriers and determination of one of most important parameters – saturated water conductivity k_s. Saturated water conductivity coefficient was determined for red ceramic brick, aerated concrete and autoclaved calcium silicate using a modified Wit apparatus, which normally is applied for soil hydraulic conductivity coefficient determination.

Obtained results confirmed the lowest conductivity feature of red brick which is expressed in the lowest value of saturated conductivity coefficient. Aerated concrete and autoclaved calcium silicate are more porous materials and thus are more hydraulically conductive.

Keywords: capillary uptake, Richards model, water transport in porous media, saturated water conductivity coefficient

Introduction

One of the models describing water transport in porous materials is a Richards equation. It is based on Darcy's law (Zaradny 1990) of saturated water transport in porous medium. According to Darcy's law, water transport is a relation of sample cross-section, hydraulic gradient and saturated conductivity coefficient *k*, determined in the described research. Darcy's model of water transport can be described with the following formula:

$$V = k_s \Delta h \tag{1}$$

Where:

k_s – saturated conductivity coefficient (Darcy's constant) [cm/s, cm/h, cm/d],
Δh – pressure gradient [cm H_2O, m H_2O].

Saturated conductivity is a characteristic feature of each material and it depends mainly on its porosity, granulometry and temperature. Values of saturated conductivity coefficient are determined experimentally and they may differ for each material many times.

Darcy's model of water transport in porous media described in this paper is mainly applied in soil water movement description, where water flow is expressed in volume units [m^3/s] and transporting force is hydraulic gradient caused by pressure difference. Anyhow it should be underlined that this model is also applied in building physics (Černý et al., 2001; Grunewald, 2000) especially in states near saturation, which may occur in the bottom parts of the buildings like funds or walls in contact to ground water, without suitable water-proof isolation.

Building materials and barriers are hardly ever in saturated states, that's why application of Darcy's model is strongly limited in building physics and more practical is to use Richards model, where water transport depends not only on the hydraulic gradient and water conductivity but also on water content. That's why in unsaturated states water velocity should be described by the following formula (van Genuchten 1980, Feddes 1997, Kowalik 1995):

$$V = -k(\theta)\nabla h \tag{2}$$

Where:

θ – volumetric water content [cm^3/cm^3],

$k(\theta)$ – hydraulic water conductivity in relation to water volumetric content [cm/s, cm/h, cm/d],

h – water pressure [cm H_2O, m H_2O].

Above formula is a Darcy's model for unsaturated states, where $k(\theta)$ is a hydraulic conductivity in relation to moisture. Water content and water pressure are combined by water retention characteristics (Mualem 1976, van Genuchten 1980, Mallants, 1997) that's why water conductivity in the above formula can be also treated as a relation of water pressure h.

Formula describing water transport in unsaturated materials is called Richards model and requires to determine hydraulic conductivity in unsaturated states - $k(\theta)$ or $k(h)$.

In the first case, hydraulic conductivity depends on volumetric water conductivity and Richards formula can be described in the following form:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[D(\theta)\frac{\partial\theta}{\partial x}\right] + \frac{\partial}{\partial y}\left[D(\theta)\frac{\partial\theta}{\partial y}\right] + \frac{dk(\theta)}{d\theta}\frac{\partial\theta}{\partial y} \tag{3}$$

Where:

$D(\theta)$ – moisture diffusivity, the product of hydraulic conductivity and moisture characteristics $k(\theta)\frac{dh}{d\theta}$.

Final element of the above formula is gravitation, which does not strongly influence the process of capillary rise. From the point of view of the building physics it may be worth to mention here, that without gravitation part this formula is equivalent to heat conductivity equation in relation to temperature (Kowalik 1995).

Another form of Richards equation is a formula in relation to hydraulic potential, which, from computational reasons is more often used in simulations, especially in multilayered objects like building envelopes:

$$C(h)\frac{\partial h}{\partial t}=\frac{\partial}{\partial x}\left[k(h)\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[k(h)\frac{\partial h}{\partial y}\right]+\frac{dk(h)}{dh}\frac{\partial h}{\partial y} \tag{4}$$

Where:

$C(h)=\frac{d\theta}{dh}$ - differential water capacity of the material [m^{-1}].

Hydraulic conductivity coefficient described in this article is determined for only saturated states, which are not typical for most of circumstances connected to water flow in building barriers, thus there are applied many mathematical and empirical models relating hydraulic conductivity to pressure potential (or moisture). Currently the most popular models are the following:

- in relation to moisture (van Genuchten 1980):

$$k(\theta)=k_s\sqrt{\theta}\cdot\left[1-(1-\theta^{\frac{1}{m}})^m\right]^2 \tag{5}$$

- in relation to pressure potential (van Genuchten 1980):

$$k(h)=k_s\frac{\left[\left(1+|\alpha h|^n\right)^m-|\alpha h|^{n-1}\right]^2}{\left(1+|\alpha h|^n\right)^{\frac{5}{2}m}} \tag{6}$$

Where:

k_s – saturated water conductivity [cm/d],

θ – volumetric water content [cm^3/cm^3],

α,n,m – empirical parameters depending on type of the porous medium.

As visible in the above formulas, determination of water conductivity coefficient in intermediate states requires determination of this parameter in saturation and then recalculation into unsaturated states using above presented formulas.

Materials and Methods

The aim of the described research was to determine saturated water conductivity coefficient (Darcy's constant). The research was conducted using laboratory technique with Wit apparatus (Wit 1967) modified by Zawadzki (Zawadzki et al. 1981) presented at Fig. 1.

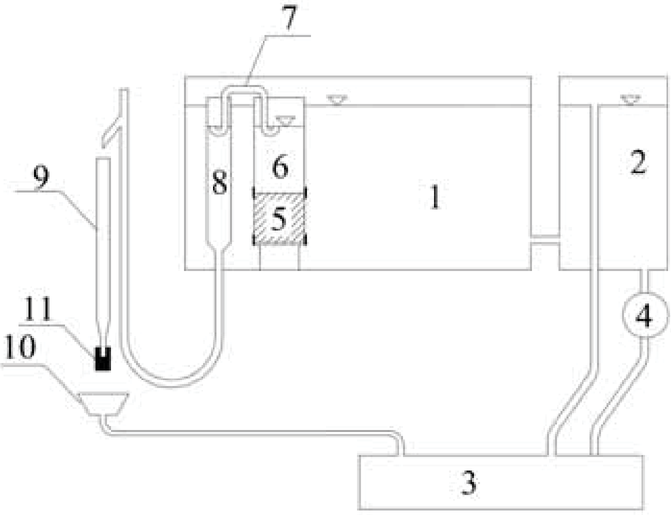

Fig. 1. Schematic of modified Wit aparatus (Iwanek 2005, Zawadzki et al. 1981): 1 – main container, 2 – overflow vessel, 3 – closed water container, 4 – electric pump, 5 – measured sample, 6 – measurement cylinder, 7 – overflow siphon, 8 – outflow siphon, 9 – burette, 10 – outflow through, 11 – rubber heel

The details of modified Wit apparatus and its service are in detail presented in [Zawadzki et al. 1981].

For the experiment a set of the following building material samples was prepared: red ceramic brick (apparent density 1600g/dm^3), cellular concrete (apparent density 400g/dm^3) and autoclaved calcium silicate (apparent density 180g/dm^3). The samples were precisely placed in measurement cylinders and sealed with bitumen insulation to eliminate any potential leaking.

In case of red ceramic brick it was necessary to modify the sample preparation methodology due to impossibility of insertion of the hard material in the traditional cylinder cover. For that aim the cuboid samples were prepared with the following dimensions: 5×5×5.8cm and externally insulated with epoxy resin to prevent unexpected water inflow to the measured material from the outside.

The whole experiment was repeated six times. Saturated water conductivity coefficient k_s was calculated using the following formula (Zawadzki et al. 1981, Iwanek 2005):

$$k_s = \frac{Q\Delta l}{F\Delta H} \tag{7}$$

Where:

Q – amount of water in time [cm^3/s],
Δl – vertical length of the sample [cm],
F – sample cross-section area perpendicular to water flow direction [cm^2],
ΔH – hydraulic loss at Δl length [cm].

Results and discussion

Below presented table shows average saturated conductivity coefficients of three examined building materials expressed in [cm/min] and [cm/day] together with standard deviations (δ).

Table 1. Saturated conductivity coefficients of examined building materials

Material	Saturated conductivity k_s			
	[cm/min]	δ [cm/min]	[cm/day]	δ [cm/day]
Red Ceramic Brick	0.00078	0.00006	1.125	0.0821
Cellular Concrete	0.00198	0.00036	2.845	0.5219
Autoclaved Calcium Silicate	0.00226	0.00042	3.253	0.6045

On the basis of the conducted research it is visible that the building material with the lowest hydraulic saturated conductivity is red ceramic brick. It is caused by the dense structure and the biggest share of solid phase in the whole volume. Cellular concrete and autoclaved calcium silicate are the materials with greater porosity and thus the value of saturated conductivity coefficient is significantly greater (two times in case of autoclaved calcium silicate).

Comparing the obtained results with the values found in the literature it should be noticed that it is hard to find values of this parameters. It is mainly caused by the fact that Richards equation is not popular model of water transport in building materials. According to data presented by Hall et all. (2001) value of this parameter varies between $3.2 \cdot 10^{-8}$ to $3.8 \cdot 10^{-9}$cm/s which means that red brick is a very inhomogeneous material with hydraulic saturated conductivity coefficient varying even 10 times.

Conclusions

Basing on the conducted experiment and obtained results, the following conclusions may be drawn:

- Richards model applied for water transport in unsaturated, porous materials is not popular in building physics to describe water movement in building materials and barriers.
- Modified Wit apparatus enables determination of saturated conductivity coefficient of building materials which is an important factor in Richards model of water transport.
- Saturated conductivity coefficients determined in the presented research can be successfully applied for water uptake simulating in building materials and barriers using Richards model.
- Among examined materials, the greatest value of saturated conductivity coefficient was determined for autoclaved calcium silicate and the lowest for ceramic brick, which means that brick is less permeable material from the other examined media.

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