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Gas permeability of pervious concrete and its implications on the application of pervious pavements

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ABSTRACT

A new, simple apparatus was developed to measure the gas permeability of pervious concrete. The apparatus was assembled to allow gas flowing through the pervious concrete sample in a pressure-steady manner. A vacuum was used to create a stable gas flow through the sample while the gas-flowing rate was gauged by a Venturi tube. The gas permeability was measured under different applied pressures and different sample-saturated conditions. It is found that the permeability of pervious concrete decreases with the applied pressure gradient but does not obey the Klinkenberg effect. The saturated degrees do not distinctively influence the gas permeability of the pervious concrete. The gas permeability varies from 10^{-9} to 10^{-10} m^2. This low permeability suggests that there is no buoyancy-driven convection inside the pervious pavements. This further implies that pervious pavements do not enhance the underlying root respiration and that the evaporation of the holding water in pervious pavements performs limited cooling effect.

1. Introduction

Pervious concrete is mixed by eliminated most or all fine aggregates from the mixture. Pervious pavements are used to allow storm water to percolate through their cavity, and to some extents, to allow roots and soils under the pavement respiring. The gas permeability of pervious concrete is thus important to the soil breathing under pervious pavements [1–3].

Gas permeability of pervious concrete has limited reported in literature, although the water permeability of permeable concrete has been measured extensively [4–7]. Gas permeability of pervious concrete, however, cannot be directly deduced from the measured water permeability, because of the gas-slippage affect or said the Klinkenberg effect [8–10]. The gas permeability of pervious concrete may be tested under experiment setups that are different from those apparatuses used to measure the gas permeability of normal concrete. This is because the gas permeability of pervious (10^{-10} m^2) is seven orders of magnitude less than that of normal concrete (10^{-17} m^2).

The main objective of this study is to measure the gas permeability of pervious concrete. A new, simple apparatus was developed to test the gas permeability of pervious concrete samples under different saturated degrees. Two permeable concrete batches were mixed for the associated tests. The dependency of the gas permeability on the applied pressure is estimated to characterize if this dependency obeys the Klinkenberg effects. Using the measured gas permeability, this paper further discusses if pervious pavements enhance the underlying root respiration and perform evaporative cooling.

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2. A new, simple apparatus for testing the gas permeability of pervious concrete

An air permeameter, as indicated in Fig. 1, is developed to measure the gas permeability of porous concrete. It applies a pressure gradient across a porous medium while the resulting flux in a steady state is gauged. The permeameter, as indicated in Fig. 1b, consists of three sections: pressure gradient indicator (H), sample section, and a Venturi tube used to calculate the associated gas flux.

During the experiment, a vacuum is used to create a gas pressure gradient that forces air flow through the sample. The air flowing rate is gauged by a Venturi tube before the vacuum (Fig. 1). In the Venturi tube (Fig. 2), the gas flowing obeys:

$$u_1 = u_2 A_2/A_1 \tag{1}$$

$$P_1 - P_2 = \rho_g(u_2^2 - u_1^2)/2 \tag{2}$$

Solving for u_1 and noting $p_1 - p_2 = \rho_l g \Delta h$, one gets:

$$u_1 = C_D \sqrt{\frac{2\rho_l g \Delta h}{\rho_g\left(\left(\frac{A_1}{A_2}\right)^2 - 1\right)}} \tag{3}$$

where ρ_l (kg/m^3) and ρ_g (kg/m^3) is the density of water and gas, respectively; g (m s^{-2}) is gravitational force; Δh (m) is the head difference read from the Venturi tube; and A_1 (m^2) and A_2 (m^2) are across-sectional areas of the venture tube at the broad and narrow sections; and C_D is the longitudinal friction loss coefficient because of the flowing gas contracted at the narrow section of the Venturi tube (Fig. 2) [11].

In the apparatus shown in Fig. 1, the air passing through the Venturi tube is equal to the air flowing through the sample; and the gas flowing rate through the sample is:

$$u_g = u_1 A_1/A \tag{4}$$

Considering the applied pressure difference is relatively small so that gas compressible components is negligible, one can compute the apparent gas permeability k_g (m^2):

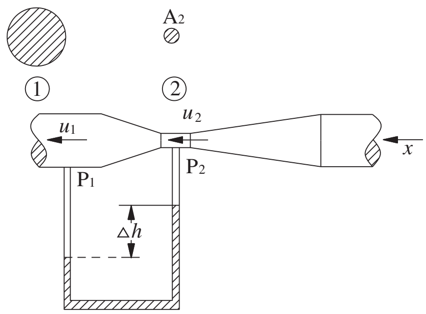


Fig. 2. A schematic show for the Venturi tube.

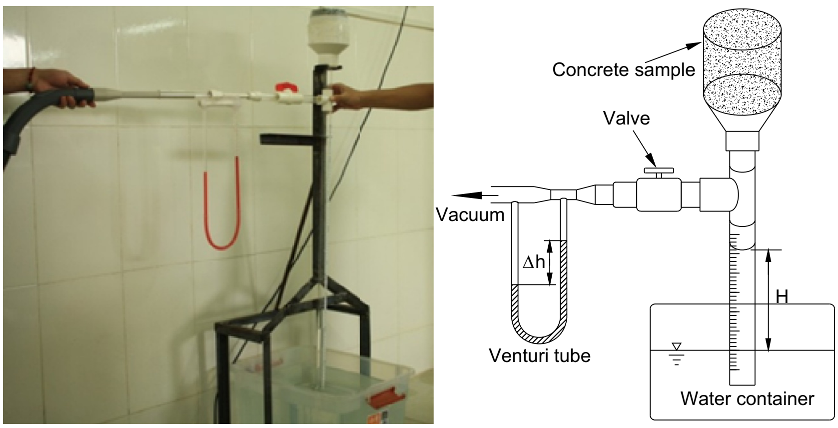
$$k_g = \frac{\mu_g L}{\rho_l g H} u_g \tag{5}$$

where μ_g (Pa s) is gas viscosity; H (m) is the water head reading from the capillary tube; A (m^2) and L (m) is the cross-sectional area and length of the sample, respectively.

Eq. (5) is available only when the gas flowing through the sample is laminar. In lab study, the gas has to flow through the sample in a sufficiently high rate so that the negative pressure in the chamber is sufficient to sustain a measurable water head in the capillary tube (H) and a readable water-head difference in the Venturi tube (Δh). Therefore, the air flow through the sample may be categorized as turbulent flow. The k_g and the pressure gradient can be correlated as Eq. (6) according to Forcheimer law.

$$\frac{\rho_l g H}{L} = -\frac{\mu_g}{k_g} u_g - c_F \frac{\rho_g}{\sqrt{k_g}} u_g^2 \tag{6}$$

where c_F is a dimensionless form-drag constant, approximately equal to 0.55 based on the work of Ward [12]. The negative sign at the right-hand side signifies gas flows from the greater pressure side. In Eq. (6), all variables are measureable except the gas permeability k_g, which can be solved by use of iterative numerical method.



(a) (b)

Fig. 1. An apparatus developed to measure gas permeability of pervious concrete; (a) experimental setup and (b) a schematic show for the air permeameter.