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Hydraulic characterization of " Furcraea andina" fibers as alternative medium for bioremediation of contaminated porous media (aquifers) by means of PRB

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Abstract

Recent studies on natural fiber development have shown the effectiveness of these fibers for removal of some heavy metals, due to the lignin content in the natural fibers which plays an important role in the adsorption of metal cations (Lee et al., 2004; Troisi et al., 2008; C. Fallico, 2010).
In the context of remediation techniques for unsaturated and/or saturated zone, an experimental approach for the hydraulic characterization of the "Furcraea andina" (i.e. Cabuya Blanca) fiber was carried out. This fiber is native to Andean regions and grows easily in wild or cultivated form in the valleys and hillsides of Colombia, Ecuador, and Peru.

1.Introduction

To build reactive permeable barriers (PRB) some natural fibers can be used (liberian fibers), like cotton, sisal, kenaf, spanish broom fibers, etc. The aim of this study is to verify the use of the furcraea andina fiber for PRB. Specifically in the present study the hydraulic characterization of this fiber was investigated.

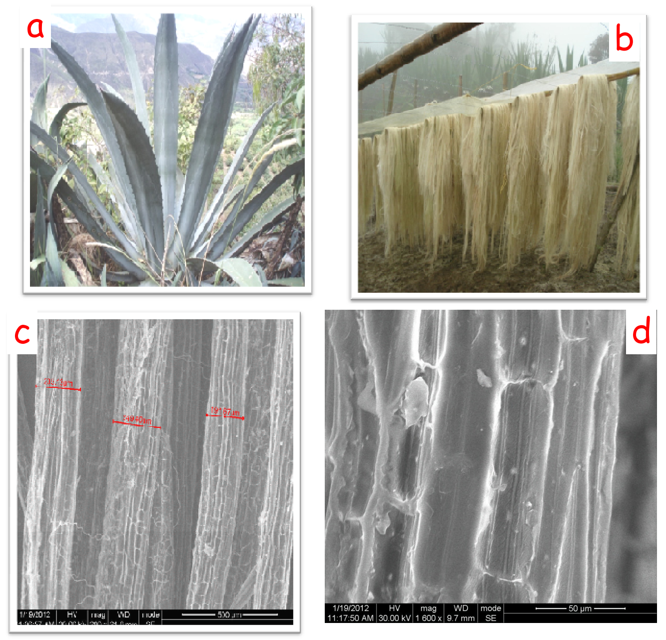

Figure 1: Different states of cabuya fibers:
a) natural plant, b) naturally extracted fibers,
c) and d) fiber filaments (SEM analysis).

Fibers of "Furcraea andina" were characterized by experimental tests to determine their hydraulic conductivity or permeability and porosity in order to use this medium for bioremediation of contaminated aquifer exploiting the physical, chemical and microbial capacity of natural fibers in metal adsorption.

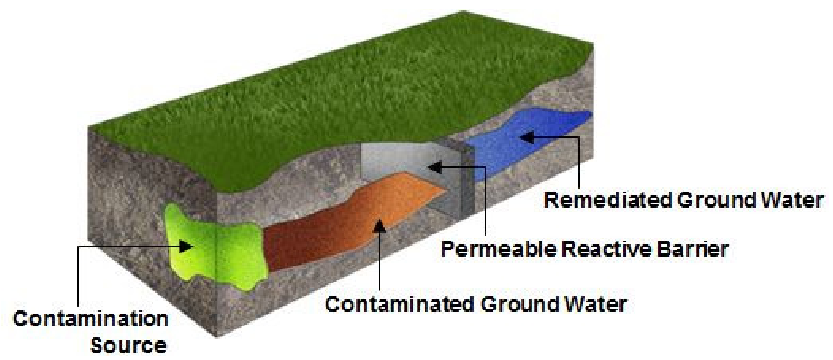

Figure 2: Permeable Reactive Barrier

2. Measurements and methods

To empirically evaluate the hydraulic conductivity, laboratory tests were carried out at constant head on the fibers manually extracted. For these tests we used a flow cell (as permeameter), containing the "Furcraea andina" fibers to be characterized, suitably connected by a tygon tube to a Marriott's bottle, which had a plastic tube that allow the adjustment of the hydraulic head for different tests to a constant value.

2.1 Experimental laboratory measurements

By this experimental measurements it was also possible to identify relationships that enable the estimation of permeability as a function of density, i.e. of the compaction degree of the fibers. Permeability measures the fluids ability to flow through porous media. The Darcy velocity (v) is defined using Darcy's law, which can be written as:

$$v = k \cdot \frac{h_2 - h_1}{L} \qquad \text{Eq.1}$$

where:
K is permeability coefficient (describes the porosity of the underground formation),
h1 is the height of the inlet head,
h2 is the height of the outlet head
Using the Eq. 1, the flow rate (Q) can be written as

$$Q = v \cdot A \qquad \text{Eq.2}$$

where:
A is the cross sectional area.
Our study was carried out for three values of hydraulic head (H), 10, 18 and 25 cm. For each constant head we repeated the test for three different rate of fiber compaction within the flow cell, corresponding to three different densities (146 kg/m³, 200 kg/m³ and 240 kg/m³). The experimental apparatus is shown in Figure 3.

Figure. 3: Experimental apparatus used for hydraulic conductivity tests

3 Results and discussion

To evaluate the effect of fibers length on permeability, we performed our tests in two different modalities: 1) use of entire natural extracted long fibers and 2) use of cut fibers with 5 cm length.
Values of hydraulic conductivity obtained for the three density values considered in two different modalities are shown in Table 1.

Hydraulic conductivity K(m/s)						
Density	entire fibers			cut fibers (5cm length)		
kg/m³	ΔH = 10 cm	ΔH = 18 cm	ΔH = 25 cm	ΔH = 10 cm	ΔH = 18 cm	ΔH = 25 cm
146	$1.74 \cdot 10^{-4}$	$7.80 \cdot 10^{-5}$	$6.89 \cdot 10^{-5}$	$4.13 \cdot 10^{-4}$	$3.12 \cdot 10^{-4}$	$1.78 \cdot 10^{-4}$
200	$8.86 \cdot 10^{-5}$	$5.79 \cdot 10^{-5}$	$4.17 \cdot 10^{-5}$	$3.96 \cdot 10^{-4}$	$1.91 \cdot 10^{-4}$	$1.33 \cdot 10^{-4}$
240	$7.49 \cdot 10^{-5}$	$4.72 \cdot 10^{-5}$	$3.22 \cdot 10^{-5}$	$1.93 \cdot 10^{-4}$	$1.21 \cdot 10^{-4}$	$6.98 \cdot 10^{-5}$

Table 1. Values of hydraulic conductivity

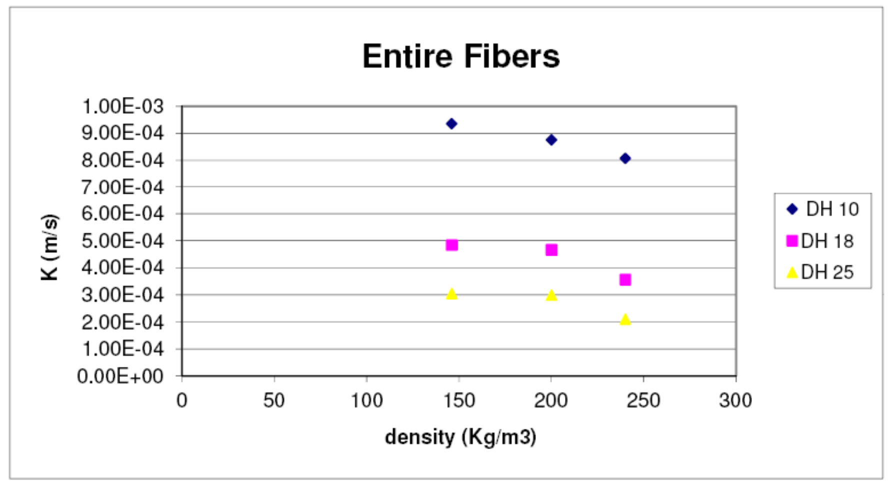

Figure 4: Permeability variation at vary density in tests with entire fibers

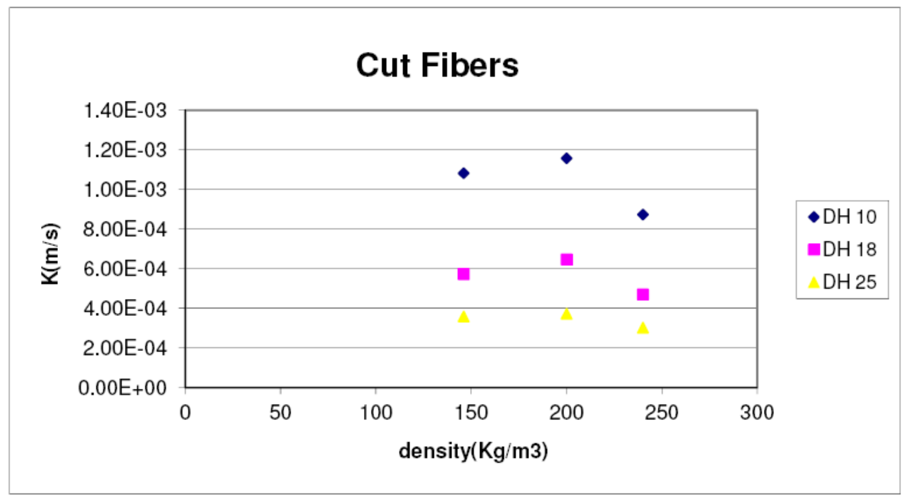

Figure 5: Permeability variation at vary density in tests with cut fibers

Analysis of the values in Table 1 shows that with increasing density of the fibers there is an increase of hydraulic conductivity. This trend is also highlighted in the graphs of Figures 4 and 5 where values of conductivity obtained for each set of density in two different modalities (entire and cut fibers) are plotted.

Interpolation of experimental results shown in Figures 4 and 5 led to the following relationships that enable the estimation of permeability (k) as a function of density (x).

Equations (3), (4) and (5) were determined for the entire fibers instead equations (6), (7) and (8) are valid for cut fibers. In parenthesis there is the corresponding hydraulic head (H).

$k = 3 \cdot 10^{-8} x^2 - 6 \cdot 10^{-6} x + 0.0008$ (H=10 cm) Eq.3
$k = 9 \cdot 10^{-9} x^2 - 8 \cdot 10^{-7} x + 0.0002$ (H=18 cm) Eq.4
$k = 3 \cdot 10^{-9} x^2 - 1 \cdot 10^{-6} x + 0.0002$ (H=25 cm) Eq.5

$k = -5 \cdot 10^{-8} x^2 + 2 \cdot 10^{-5} x - 0.001$ (H=10 cm) Eq.6
$k = 5 \cdot 10^{-9} x^2 - 4 \cdot 10^{-6} x - 0.0008$ (H=18 cm) Eq.7
$k = -8 \cdot 10^{-9} x^2 + 2 \cdot 10^{-6} x - 0.00001$ (H=25 cm) Eq.8

The results obtained experimentally on the values of permeability assume greater importance when compared to the values of hydraulic conductivity already known from the literature for different soil types. This comparison shows that, for the density values with which the tests were carried out, obtained conductivity values are typical of a soil constituted mainly of sand (very fine) having a value between $10^{-6} \div 10^{-4}$ (m/s) (Celico, 1986; Hamill and Bell, 1986).

4. References

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