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POLLUTANT MIGRATION THROUGH FRACTURED POROUS MEDIA

P. Royer¹, J.-L. Auriault¹, J. Lewandowska², C. Serres³

¹ Laboratoire Sols, Solides, Structures (3S), UJF, INPG, CNRS, Grenoble, France.

² Laboratoire d'études des Transferts en Hydrologie et Environnement (LTHE), UJF, INPG, CNRS, IRD, Grenoble, France.

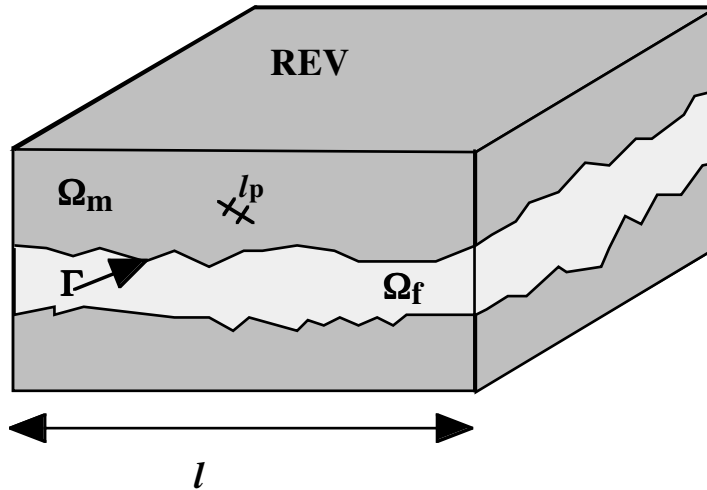
³ Institut de Protection et de Sûreté Nucléaire (IPSN), Fontenay-aux-Roses, France.

1. Introduction

This work is aimed towards deriving mathematical models that describe pollutant migration through fractured porous media. A homogenisation method is used, i.e. macroscopic models are rigorously deduced from the physical description which is valid within a Representative Elementary Volume (REV). The fundamental assumption behind homogenisation is the separation of scales which is expressed by: $l/L = \varepsilon \ll 1$. In the present work, l is the characteristic size of the REV, i.e. at the fracture's scale and L is the characteristic macroscopic size. The approach introduced in [1] is used. This methodology is on the basis of definition and estimation of dimensionless numbers arising from the description at the REV's scale. The domains of validity of the derived macroscopic descriptions is provided by means of the orders of magnitude of the local dimensionless numbers.

2. Dimensionless local description

The REV consists of a porous matrix domain, Ω_m , and a fracture domain, Ω_f , whose common boundary is denoted by Γ . The medium is saturated by water and a solute is diluted in water. In the fracture's domain fluid flow is described by Stokes equations and solute transport by the diffusion-convection equation. In the porous matrix, the filtration of the liquid is described by Darcy's law and the solute transport is described by a diffusion-advection law that accounts for diffusion in the solid and diffusion and convection in the pores. Note that the behaviour at the porous matrix scale of the process of diffusion in both the solid and the micropores may be different from that considered here [2].



The methodology consists in writing the local description in a dimensionless form and then in estimating the dimensionless numbers with respect to the scale-ratio ε . This leads to the following formulation of the equations:

In the fractures (Ω_f):	In the porous matrix (Ω_m):	On the boundary (Γ):
$\varepsilon^2 \mu \Delta \vec{v}_f - \vec{\nabla} p_f = \vec{0}$ $\vec{\nabla} \cdot \vec{v}_f = 0$ $N \frac{\partial c_f}{\partial t} - \vec{\nabla} \cdot (\vec{D}_f \vec{\nabla} c_f - P e_f c_f \vec{v}_f) = 0$	$\vec{v}_m = -\vec{K}_m \vec{\nabla} p_m$ $\vec{\nabla} \cdot \vec{v}_m = 0$ $N \frac{\partial c_m}{\partial t} - \vec{\nabla} \cdot (\vec{D}_m \vec{\nabla} c_m - \alpha^2 P e_f c_m \vec{v}_m) = 0$	$\vec{v}_f = \alpha^2 \vec{v}_m$ $p_f = p_m$ $(\vec{D}_f \vec{\nabla} c_f) \cdot \vec{n} = (\vec{D}_m \vec{\nabla} c_m) \cdot \vec{n}$ $c_f = c_m$

This local description depends upon the following parameters: $Pe_f = \frac{LV_{f_c}}{D_{f_c}}$; $N = \frac{L^2}{D_{f_c}T_f}$; $\alpha = \frac{l_p}{l}$.

Pe_f is the Péclet number in the fractures. l_p is the characteristic pore-size. V_{f_c} and D_{f_c} are characteristic values of the fluid velocity and of the molecular diffusion in the fractures, respectively. T_f is the characteristic time of the transport process in fractures.

It can be shown that the cases of interest, i.e the cases that lead to distinct macroscopic behaviours are the following:

Case 1: $Pe_f = O(\varepsilon)$; $N = O(1)$; $\alpha = O(\varepsilon)$ (predominant diffusion in the fractures)

Case 2: $Pe_f = O(1)$; $N = O(1)$; $\alpha = O(\varepsilon)$ (equivalent diffusion and convection in the fractures)

Case 3: $Pe_f = O(\varepsilon^{-1})$; $N = O(\varepsilon^{-1})$ (predominant convection in the fractures)

Case 3.a: $\alpha = O(\varepsilon^{1/2})$; Case 3.b: $\alpha = O(\varepsilon)$.

3. Derived upscaled models

The derived macroscopic models are the following:

Fluid flow

$$\vec{V}_f = -\mathbf{K}_f \vec{\nabla} P$$

$$\vec{\nabla} \cdot \vec{V}_f = 0$$

Solute transport

$$\text{Case 1: } \frac{\partial C}{\partial t} - \vec{\nabla} \cdot (\mathbf{D}_{eff} \vec{\nabla} C) = 0 \quad (\text{purely diffusive behaviour})$$

$$\text{Case 2: } \frac{\partial C}{\partial t} - \vec{\nabla} \cdot (\mathbf{D}_{eff} \vec{\nabla} C - C \vec{V}_f) = 0 \quad (\text{convection-diffusion})$$

$$\text{Case 3.a: } \frac{\partial C}{\partial t} - \varepsilon \vec{\nabla} \cdot [\mathbf{D}_{disp} \vec{\nabla} C - \frac{1}{\varepsilon} C (\vec{V}_f + \varepsilon \vec{V}_m)] = 0 \quad (\text{dispersion with influence of the porous matrix})$$

$$\text{Case 3.b: } \frac{\partial C}{\partial t} - \varepsilon \vec{\nabla} \cdot (\mathbf{D}_{disp} \vec{\nabla} C - \frac{1}{\varepsilon} C \vec{V}_f) = 0 \quad (\text{dispersion})$$

\mathbf{K}_f is the effective permeability tensor. \mathbf{D}_{eff} is the effective diffusion tensor and \mathbf{D}_{disp} is the apparent dispersion tensor. They are defined by boundary-value problems to be solved over the REV. \mathbf{K}_f is a symmetrical tensor and depends only upon the geometry of the REV. \mathbf{D}_{eff} is also symmetrical and depends upon the cell-geometry and the molecular diffusion. \mathbf{D}_{disp} is not symmetrical in the general case and depends upon the pressure gradient.

4. References

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