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1. Introduction

The accurate comprehension of flow and mass transport in porous media is of primary concern to improve our understanding of pollutant transfer through soils. Surface soils often present preferential flow paths allowing the fast movement of the various substances carried by water. These flow paths can stem from structural heterogeneities such as macropores (i.e. single pores having a larger diameter and a greater continuity than matrix pores). Macropores may result from biological activity (wormholes, rootholes) or from some physical process (cracks, fissures) and are known to strongly influence the breakthrough of solutes in soils [1]. Indeed, the preferential flow in a saturated porous medium displaying a macropore is much faster than would be predicted from the sole knowledge of the average medium properties and the application of Darcy's law. Physical non-equilibrium models extending Darcy's or Richards' laws (such as multiple porosity/permeability models) have been proposed to take into account the different flow types that may exist in heterogeneous soils [2]. However, these models are based on the equivalent homogeneous medium approach and are not always reliable when it is essential to have knowledge of the individual flow paths.

2. Experimental set-up

In this work, we have investigated the influence of the flow rate and the viscosity of the carrying fluid on nonreactive solute transport in a model heterogeneous porous medium under saturated conditions and steady flow. Injection at various flow rates have been performed in a column (5 cm diameter, 14.5 cm height) filled with glass beads (0.6 mm mean diameter) glued together. A 3 mm diameter Teflon rod inserted along the axis of the column during the preparation of the medium was removed when the surrounding bead packing was sufficiently consolidated. Breakthrough has been monitored during each injection by measuring the solute concentration at the outlet of the system, whereas transport within the column itself has been investigated by magnetic resonance imaging.

3. Results

Experiments have shown that nonreactive solute transport is strongly affected by physical non-equilibrium induced by the preferential flow occurring in the macropore. The shape of the experimental breakthrough curves (BTCs) is influenced both by the flow rate and the coefficient of molecular diffusion of the solute. When the mean residence time of the solute in the macropore is small enough, solute transport in a macroporous column can be considered as isolated within the macropore, with virtually no solute exchange with the neighboring porous matrix. However, when the mean residence time increases, a non-negligible fraction of solute is exchanged between the macropore and the surrounding matrix. Magnetic resonance images indeed revealed the occurrence of solute exchange between the macropore and the neighboring packing. The timescale associated with this exchange stresses the role played by lateral molecular diffusion. In this high residence time regime, classical transport models (e.g. the convection-dispersion equation or the mobile-immobile model) are not able to reproduce correctly the experimental BTCs and the best-fit parameter values are unphysical. Finally, in order to get a quantitative and sound understanding of solute exchange between the macropore and the surrounding porous matrix, we implemented a microscopic advection-diffusion model, which had the added benefit of allowing the calculation of satisfactory numerical BTCs.

References

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