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ORIGINAL PAPER

The use of a mixed scheme: mixed hybrid finite elements method/finite volumes (MHFE/FV), for the modeling of contaminants transport in unsaturated porous mediums

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Abstract This work is intended for the development of a numerical method to simulate flows and solute transport in multiphasical porous medium taking into consideration the interaction of solid/solute. More precisely, the studied problem is modeled by a coupled system composed of an elliptical equation (for the flow) and an equation convection–diffusion–reaction (for the transfer). Numerical simulations were realistic for two-dimensional problems confirming the stability and efficiency of the combined scheme in the characterization of a pollutant transport through an unsaturated zone of an industrial site.

Keywords Unsaturated sols · Model · Modeling · Contaminated aquifer · Finite element · Finite volume

Introductions and problematic

In the classical theory of drainage, flows are supposed to be vertical in the unsaturated zone (*USZ*) and horizontal in the aquifer. This is the concept of the mixed layer. However, many authors (Vauclin et al. 1979; Clement et al. 1996; Romano et al. 1999; Kao et al. 2001; Silliman et al. 2002) underline the existence of a significant part of the infiltration that flows out horizontally in the USZ of the draining systems. The importance of the unsaturated zone as an integral part of the hydrological cycle has been recognized a long time ago. The zone plays an inextricable role in many aspects of hydrology, including the infiltration, soil humidity storage, evaporation, absorption of plant water, underground aquifer supplying, and streaming and erosion waters. The interest of the unsaturated zone has increased considerably because of increasing worries about the quality of the underground environment, which is affected by agricultural, industrial and municipal activities. In these fields, calculations and numerical simulations are fundamental because the experiments are very difficult, or else impossible; on the other hand, predictions are vital.

The application of the classical conforming finite element method to fluid flow in porous media, in general, does not locally conserve mass (Herbin and Kroner 2002) due to its global continuity requirement. Many specialized methods have been developed to resolve these difficulties. Eulerian methods use fixed spatial grids and incorporate some form of upstream weighting or other dissipation techniques in their formulations. Hence, they can eliminate the nonphysical oscillations present in the standard finite difference and finite element methods. Some of the Eulerian methods—such as the Godunov scheme, the total variation diminishing schemes, and the ENO/WENO schemes—can resolve shock discontinuities from the nonlinear hyperbolic conservation laws. Characteristic methods take advantage of the hyperbolic nature of the convection–diffusion equations by utilizing a characteristic tracking to treat the advective component of the governing equation. These methods symmetrize the governing equations and significantly reduce the temporal truncation errors. Thus, they allow large time steps to be used in numerical simulations without loss of accuracy, and lead to a greatly improved efficiency. However, most characteristic

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