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Discussion Paper

Numerical modeling of colloidal transport in Fractured porous media with double layered fracture-skin. Discussion of a paper by N. Natarajan and G. Suresh Kumar, Journal of Geo-Engineering Sciences, 1(2) 83-94, 2014.

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The paper by Natarajan and Suresh Kumar represents a contribution to the numerical modeling of colloids transport in fluid saturated rock, with special emphasis on the way a second fracture-skin may be account for, and how its presence would affect the colloidal transport mechanism along the fractured porous media. A main conclusion drawn by the authors from their analysis is that the presence of a second layer of fracture-skin has a marginal effect on the transport mechanism of colloids. Leaving aside Section 2, which is devoted to the description of governing equations for colloid transport along the fracture and diffusion into fracture-skin layers and rock matrix, as well as Section 3 that summarizes the implicit finite difference scheme used to solve the coupled non linear governing equations, we shall focus our comments on Section 4.

Referring to Fig. 1 of the original paper, the governing equations for colloidal transport in the fracture ($0 \leq x \leq L$ $0 \leq z \leq b$) is

$$\begin{cases} \frac{\partial}{\partial t}(C + \bar{\sigma}_c) + V_c \frac{\partial C}{\partial x} - D_c \frac{\partial^2 C}{\partial x^2} + Q_c/b = 0 \\ \frac{\partial \bar{\sigma}_c}{\partial t} = \lambda_f V_c \, C - R_{mb} \, \bar{\sigma}_c \end{cases} \tag{1}$$

where $C = C(x, t)$ is the colloidal concentration in the fracture (immobile colloids), $\sigma_c = b\,\bar{\sigma}_c$ is the concentration of colloids attached to the fracture wall surface, V_c is the average colloid velocity, D_c is the dispersion coefficient of colloids. Parameters λ_f and R_{mb} denote respectively the filtration and remobilization coefficients of colloids. The source term Q_c in Equation (1) stands for the colloids diffusion flux from fracture into the fracture-skin.

The governing equations for colloid transport in the first fracture-skin layer ($b \leq z \leq d_1$), the second fracture-skin layer ($d_1 \leq z \leq d_2$) and in the rock matrix layer, may be conveniently rewritten as:

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$$\frac{\partial C_i}{\partial t} = \kappa_i \frac{\partial^2 C_i}{\partial z^2} \qquad \text{with } i = 1,\ 2,\ mat \tag{2}$$

where $C_i = C_i(x,\ z,\ t)$ is the concentration of the colloids in ith-layer. Parameter κ_i is defined by the ratio

$$\kappa_i = \frac{D_{CPi}}{1 + Kd_{CPi}} \tag{3}$$

where D_{CPi} is the diffusion coefficient of colloids into the ith - layer and Kd_{CPi} is the sorption partition for colloids within the ith - layer.

The transport of colloids in the fractured porous medium is defined by the set of non-linear differential equations (1) and (2), together with the initial and boundary conditions. The above mathematical formulation results in a highly coupled problem through the boundary conditions at the interfaces between the different components of the rock porous medium, as well as through term Q_c in Equation (1).

This brief, but necessary, presentation calls for the following remarks.

(1) The conclusion drawn by the authors regarding the marginal role of a second fracture-skin layer on the colloids transport mechanism, appears at first glance questionable from the physical viewpoint. This statement is actually supported by very few numerical simulations, which were performed for particular model data. Based on physical considerations or on theoretical analysis of the governing equations, a comprehensive approach would seek to first define the key parameters that control the transport mechanism of colloids. Alternatively, intensive campaign of numerical simulations should be undertaken to clarify the role of a second fracture-skin layer. Otherwise, the conclusion could be considered as only a numerical speculation, which has to be corroborated.

(2) Still referring to the same above issue, it can be emphasized that while the conclusion drawn by the authors would not be valid in the general case, the fact that the transport of colloids is slightly affected by the presence of a second fracture-skin layer is straightforward consequence of particular model data used for simulations, and could thus be predictable in advance. As a matter of fact, the data parameters reported in Table 2 indicate that porosity and diffusion coefficient of the first fracture-skin layer are much smaller than those of second fracture skin layer. In some extent, the first fracture-skin is acting like a barrier for colloids diffusion.

(3) Considering that L_f is a characteristic length of colloids transport in the fracture, the corresponding governing equation (1) can be rewritten in terms of normalized spatial position $\bar{x} = \frac{x}{L_f}$:

$$\frac{\partial C}{\partial t} + \frac{V_c}{L_f}\frac{\partial C}{\partial \bar{x}} - \frac{D_c}{L_f^2}\frac{\partial^2 C}{\partial \bar{x}^2} + \frac{\partial \bar{\sigma}_c}{\partial t} + Q_c/b = 0 \tag{4}$$

which allows for ranking the contributions of diffusion and convective terms to colloids transport along the fracture. The above equation indicates that convection phenomenon is principally responsible of colloids transport when $D_c \ll V_c L_f$, while diffusion is predominating when $D_c \gg V_c L_f$. Considering the values adopted in Table 2, this reasoning shows that the simulations made by the authors could have been performed neglecting the term $D_c \frac{\partial^2 C}{\partial x^2}$.

(4) the last remark is related to the general situation where both convective and diffusion terms contribute to colloids transport along the fracture. In this case, Equation (1) can be conveniently reformulated by introducing

$$X = x - V_c t \tag{5}$$

and expressing the colloidal concentration under the form $C(x, t) = \tilde{C}(X, t)$, it is readily shown that

$$\frac{\partial \tilde{C}}{\partial t} - D_c \frac{\partial^2 \tilde{C}}{\partial X^2} + \frac{\partial \tilde{\sigma}_c}{\partial t} + Q_c/b = 0 \tag{6}$$

The main advantage of the above form lies in the fact that only diffusion-like term is present in (6), which makes it formally similar to the governing Equations (2).