Simulation of Mass-transfer Process in Porous Media with Complex Shape

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1 Introduction

Some rare minerals and metals are extracted by underground leaching method. Thus sorption extraction of minerals on mass-transfer devices with ionite resines is the widespread method. The sorber which scheme is sketched in Fig. 1 makes wide use on practice.

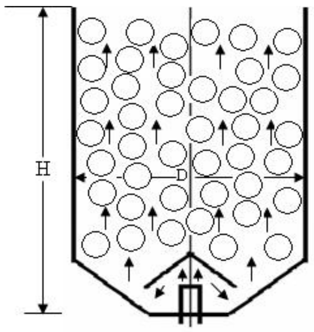

Fig. 1 Scheme of sorption column

The sorber represents a cylindrical column, which height is H and diameter – D. The sorber is filled by a layer of ionite sorbents in the form of spherical porous granules in diameter d. The solution with sorbing mineral is pumped over through a column with the certain velocity. The charge (or average velocity) of solution defined from kinetic parameters of sorption. A cone barrier located in front of pipe is intended for achievement of uniform distribution of a solution across a column. Sorption proceeds until output concentration of a mineral does not become below some limiting value.

2 The formulation of a problem

It is supposed that filtration of passive solution in sorption column is described by the equations of fluid dynamics in a granular layer [1]

$$div\vec{V} = 0, \qquad \alpha\vec{V} = -\nabla(P/\rho + zg), \qquad (1)$$

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$$\alpha = \frac{633\nu\tau}{d^2}, \quad \tau + \varepsilon = 1, \tag{2}$$

where $\vec{V}$ - velocity of solution, P - pressure in porous media, ρ - density of solution, z - vertical coordinate in cylindrical system of coordinates, g - gravity acceleration, ν -kinematic viscosity of solution, d - diameter of granules, τ - volumetric concentration of granules, ε - porosity of layer filled by granules. Mineral sorption process in a reactor is described by the following non-stationary equations

$$\frac{\partial C}{\partial t} + \vec{V} \cdot gradC = -\frac{\rho}{\varepsilon}\frac{\partial \overline{C}}{\partial t} + div(D\, grad\, C), \tag{3}$$

$$\rho \frac{\partial \overline{C}}{\partial t} = \beta\left(C - \frac{\overline{C}}{K_d}\right), \tag{4}$$

where C - volumetric concentration of a mineral in a solution, $\overline{C}$ - mass concentration of a mineral in firm granules, β - velocity of transition of a mineral between dissolved and firm phases, K_d - coefficient of equilibrium, D - tensor of diffusions with nonzero diagonal coefficients. In computation it is accepted, that, $D_z = D_m + \delta_z u$, $D_r = D_m + \delta_r \upsilon$, $\delta_z = 1.8d$, $\delta_z = 0.7d$, D_m - coefficient of molecular diffusion, d = 0.5 mm, ε = 0.4. Volumetric concentration of a mineral at an input in a solution is 0.136 g/l. Admissible volumetric concentration of mineral on an output is no more 0.057 g/l. Boundary condition on wall:

$$\vec{V} \cdot \vec{n}\Big|_S = 0, \qquad \frac{\partial C}{\partial n}\Big|_S = 0 \tag{5}$$

Fluid velosity and volumetric concentration of a mineral in a solution on inlet of sorber are set:

$$(\vec{V} \cdot \vec{n}) = u_0, \qquad C\big|_{t=0} = C_0 \tag{6}$$

At the initial time the column is filled by a solution and sorbent which is not containing a mineral:

$$C\big|_{t=0} = 0, \qquad \overline{C}\big|_{t=0} = 0. \tag{7}$$

The system of the nonlinear equations (1) - (4) with these boundary and initial conditions (5) – (7) is solved with application of numerical methods. The fictitious domain method [2] is used for simulation the solution filtration in a column with complex geometry. Kinetic parameters of mineral sorption β and K_d are defined by comparison of computations results with data of physical experiment [2]. In experiment of filtration and sorption processes are as much as possible approached to 1D case. On fig. 2 comparison of the received results of a mineral concentration in a solution with experimental data on different distances from an input in a column is shown. At values of parameters and β = 1500 kg/(m^{3}s) and K_d = 400 m available the satisfactory consent of

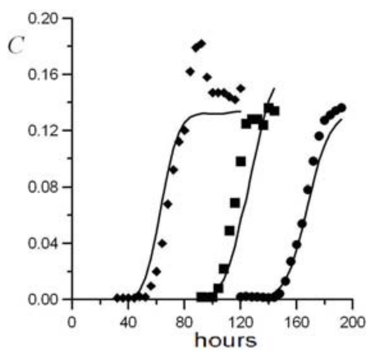

Fig. 2 Comparison of the received results on sorption kinetics with experimental data

settlement data with experimental data.

3 Results

Numerical results for distribution of pressure shown on Fig. 3. And for isoline of mass concentration of a firm phase shown on Fig. 4, that it with different values in the left half (the right half is mirror symmetric, i.e. axisymmetric) of column cut on a vertical.

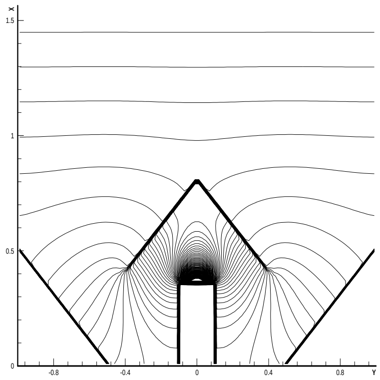

Fig. 3. Distribution of pressure

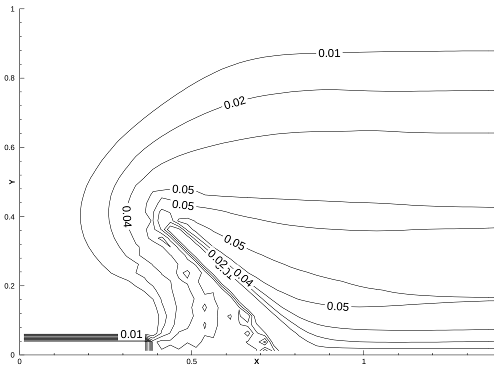

Fig. 4. Distribution of mass concentration of a firm phase

References

[1] M.A. Goldshtik (1984). Transfer processes in granular layer. Novosibirsk.

[2] Ch. Zheng, P.Wang (1999). MT3DMS, A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion and Chemical.