Substance Transfer in a Porous Medium with a Small Amount of Homogeneous Salt Modeling

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Abstract:

The salt-transfer problem in a porous media with piecewise uniform salinity is numerically solved in this paper. There are two scenarios to consider: 1) a salt solution-saturated stationary zone; 2) a dry stratum with piecewise homogenous salinity. The distribution of substance concentration and the amount of adsorbed substance are determined based on the numerical solution of the problem. It has been found that substance adsorption has an effect on salt-transfer properties.

Key words: substance adsorption, hydrodynamic dispersion, internal mass transfer, zones with moving and stationary liquid, porous medium, substance transfer.

Introduction. The research into the issues of substance transport in a porous media is crucial. During oil reservoir waterflooding, injected water can react with specific reservoir rock components, allowing these components to be transported to the aqueous phase. On the one hand, this alters the pore space structure and, as a result, the reservoir's filtration qualities, while on the other, it alters the composition and properties of the injected water behind the zone of its contact with the rock. The subterranean leaching of rocks in the mining of ore minerals presents a similar difficulty[1].

On both microscopic and macroscopic scales, strata are frequently diverse in content and structure. In modeling the processes of fluid motion and material transfer in them, macroscopic heterogeneity is schematized in a variety of ways. Layered, zonally heterogeneous structures, in particular piecewise homogenous structures, are the most common. It's worth noting that heterogeneity refers to the reservoir's lithological composition as well as its filtration-volume features.

[2] considers matter movement in a porous medium with piecewise homogenous salinity. When water interacts with the rock, the salt components dissolve and move into the aqueous phase. The dissolved salts are carried along with the water as it travels through the formation. The most common mode of transport is convection-diffusion.

Methods and materials. The paper investigates the transport of materials through a porous media with piecewise homogenous salinity, taking into account the dissolved substance's adsorption on the rock's surface. Adsorption kinetics are described by linear and nonlinear first-order equations.

A one-dimensional porous medium consisting of two parts is considered:

1) with transit pores with porosity m_1 and

2) saturated with stagnant, mineralized water with porosity

m_2, $m = m_1 + m_2$. The distribution of salts in it is piecewise homogeneous. Schematically, such a layer is depicted in fig.1.

When the solution with a certain concentration is fed into the formation, a mobile front $x_0(t) = \frac{vt}{m_1}$ is formed - the front of penetration of the injected solution through the section. The salts are supposed to be dissolved in the stagnant zones, and the intradiffusion mass transfer between the mobile and stationary zones is indefinitely fast [2]. In the absence of a stagnant zone, it is possible that the reservoir rock contains salt crystals, which instantly pass into the solution at the moment when the a $x_0(t)$ front approaches them.

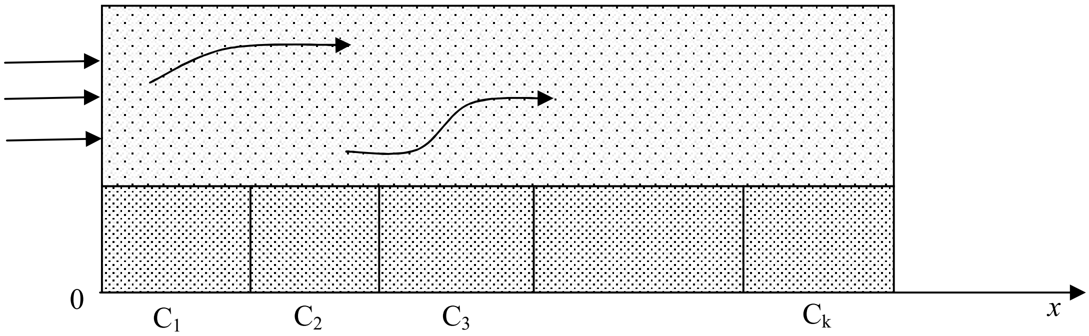


Fig.1. Schematic of a reservoir whose stagnant zone has a piecewise homogeneous salinity.

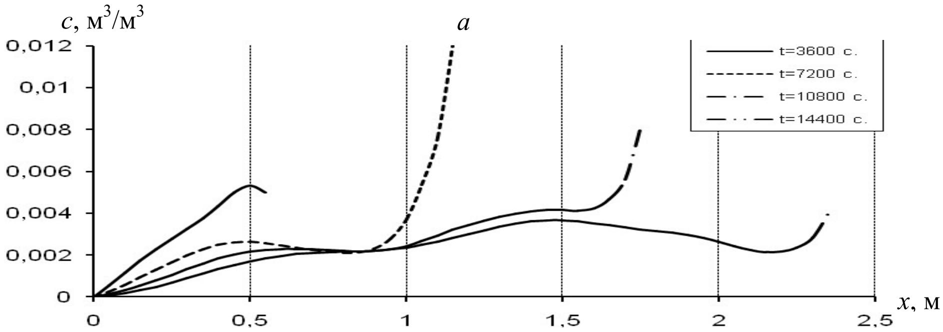
The material balance equation is taken as [3, 4]

$$m_1 \frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} + \beta \frac{\partial S}{\partial t} = D \frac{\partial^2 c}{\partial x^2}, \quad (1)$$

Where c –substance concentration, м³/м³; D – hydrodynamic dispersion coefficient, м²/с; m_1 – porosity in the zone with the moving fluid; S – concentration of the adsorbed substance in the zone with the moving liquid, м³/кг; v – filtration speed, m/c; x – coordinate,m; β – total density of porous medium, kg/m³.

The kinetics of nonequilibrium adsorption of a substance is determined by a first-order equation,[5]

$$\frac{\partial S}{\partial t} = k_1 \frac{m_1}{\beta} c - k_2 S, \quad k_1,\ k_2 \text{ - const.} \quad (2)$$



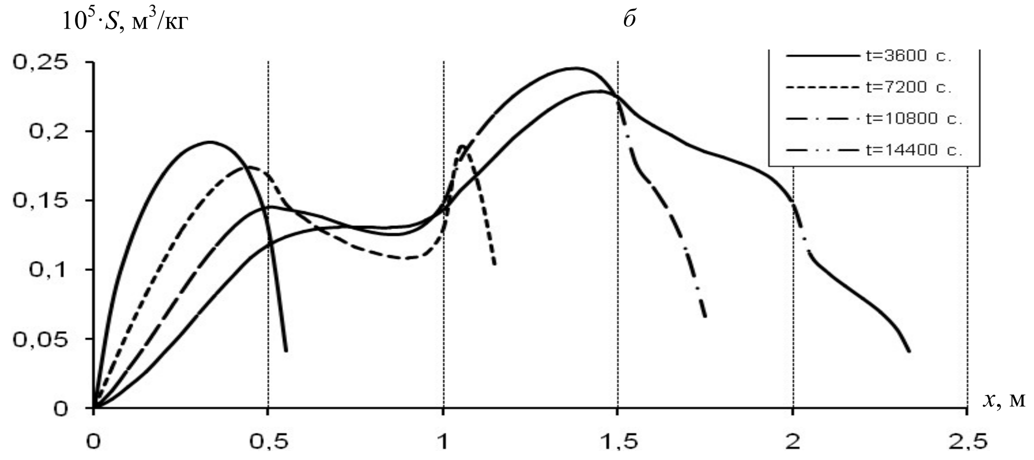


Fig. 2. Concentration profiles $c(a)$, S (б) at $k_1 = 2 \cdot 10^{-3}$ c^{-1}, $k_2 = 5 \cdot 10^{-4}$ c^{-1}, $\alpha = 2000$ c $D = 3 \cdot 10^{-6}$ m^2/c at various points in time.

As an example, consider a reservoir whose stagnation zone consists of five parts, with boundaries $x_l = 0{,}5l$, $l = \overline{1{,}5}$, hence the length of the reservoir L = 2,5 m. The transfer process is investigated at such time ranges that $x_0(t) \le L$ is performed. Each part of the stagnation zone has a fixed solution with a concentration of c_i, $i = \overline{1{,}5}$. From the end of the $x = 0$ reservoir, pure fluid, i.e., fluid without substance, is supplied. Then the initial and boundary conditions of the problem look like

$$c(0, x) = 0, \tag{3}$$

$$c(t, 0) = 0,\ t > 0, \tag{4}$$

$$c(t, x_0(t)) = c_0 + \sum_{l=1}^{k} (c_l - c_{l-1}) \eta(x_0(t) - x_{l-1}),\ \ x_{l-1} \le x_0(t) \le x_l,\ k \le 5, \tag{5}$$

Where c_0 - arbitrary quantity, $\eta(x)$ - single Heaviside function, $x_0 = 0$.

The task (1) - (5) is solved numerically using the difference method [6]. The distribution of salt concentrations in the stagnation zone is as follows:

$c_1 = 10^{-2}$, $c_2 = 5 \cdot 10^{-3}$, $c_3 = 12 \cdot 10^{-3}$, $c_4 = 8 \cdot 10^{-3}$, $c_5 = 4 \cdot 10^{-3}$.

Results. Some calculation results are shown in Fig. 2. As can be seen from the results, the heterogeneous distribution of salts in the stagnant zone leads to an uneven distribution of salt concentration in the mobile solution and their adsorption. Concentration gaps in the stagnant zone at the boundaries x_l are eroded over time and in the profiles c и S and they are smoothed out. The use of nonlinear adsorption kinetics, other things being equal, leads to an increase in adsorption values, due to which the concentration of the solution in the mobile zone decreases.

Let us now consider the case of a dry piecewise homogeneous formation. Then it is possible to take $m_2 = 0$, i.e. there is no stagnant zone with high water-holding capacity. The reservoir rock contains crystalline salts with a piecewise homogeneous distribution, as given above. When the fluid comes in contact with the rock, the salts dissolve instantly and pass into solution.

Conclusion. Thus, a diffusion flux of salts is formed at the wetting front. In this case, instead of condition (5) we take

$$D\frac{\partial c(t,x_0(t))}{\partial x}=\left[c_0+\sum_{l=1}^{k}(c_l-c_{l-1})\eta(x_0(t)-x_{l-1})\right]x_0^{'}(t). \qquad (6)$$

Some results of numerical solution of the problem (1) - (4), (6) are shown in fig. 3. Figure 3 corresponds to linear adsorption kinetics.

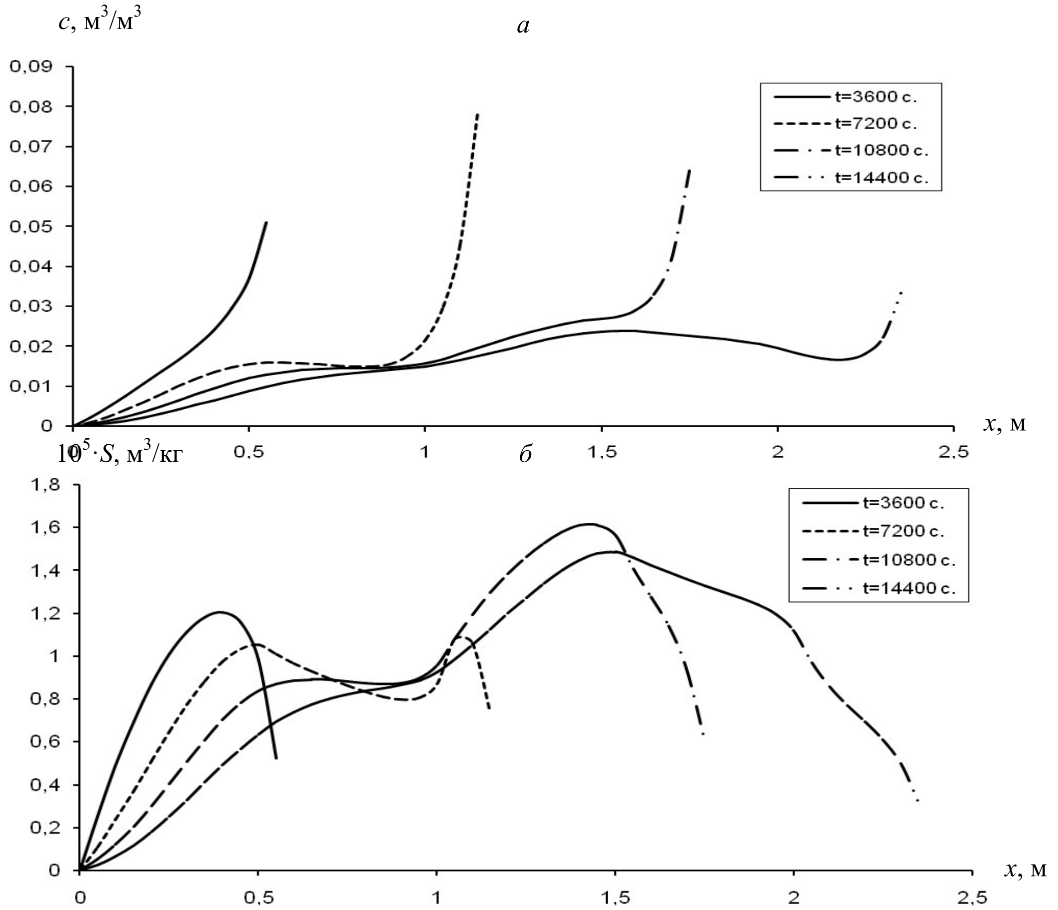


Fig.3. Concentration profiles *c*(*a*), *S* (*б*) at $k_1 = 2\cdot10^{-3}$ c^{-1}, $k_2 = 5\cdot10^{-4}$ c^{-1}, $\alpha = 2000$ c, $D = 3\cdot10^{-6}$ m^2/c at various points in time.

Setting the flux of matter as opposed to the concentration at the wetting front $x_0(t)$ leads to a concentration field with noticeably larger values. The adsorption of the substance increases accordingly .(Fig. 3) When the value of the dispersion coefficient *D* decreases, both the concentration values themselves and its gradient significantly increase. Accordingly, the adsorption also increases. Other things being equal, the nonlinear kinetics leads to stronger adsorption effects, due to which the concentration of the solution decreases compared to the linear kinetics. The discontinuities of the concentration gradient at points x_l are quickly smoothed out..

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