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STUDY OF URANIUM EXTRACTION PROCESS BY THE *IN-SITU* LEACHING METHOD

In-situ leaching is a method for development of ore deposits without lifting the ore to the surface by selective transfer of ions of natural uranium into productive solution in subsurface. This method is realized by drilling wells through the ore deposit, pumping into leaching solution and metal-laden solution pumped back to the surface, and is extracted in a processing plant. The refine solution after addition solute component sends to the underground by injecting well, as illustrated in Figure 1.
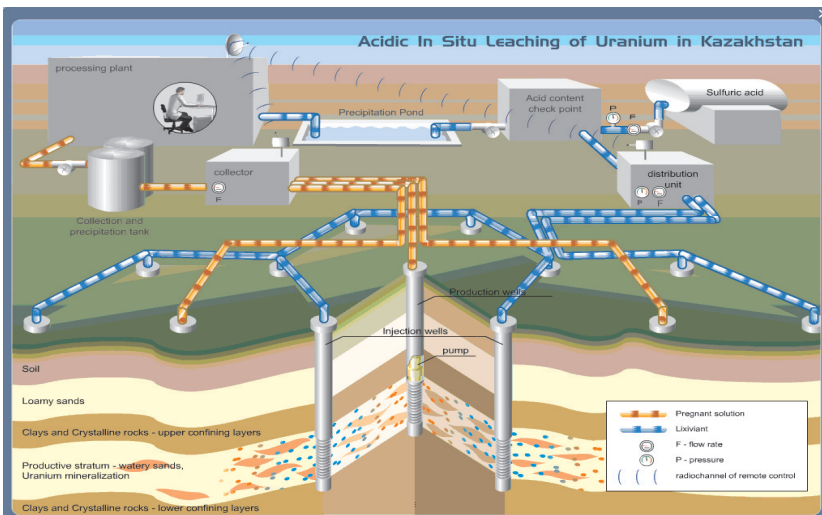

Fig. 1. Pictorial representation of the ISL process

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There are two main options for the leaching chemistry – acid or alkaline solutions. In general, acid solutions (such as sulfuric acid) will extract a higher proportion of uranium and at faster rates than alkaline solutions (such as sodium or ammonia bicarbonate). Solution of sulfuric acid and salt carbonate of ammonium, sodium, calcium are used as a reagent during the uranium mining. All uranium deposits in Kazakhstan are mining by in-situ leach method using sulfuric acid solution.

Under oxidizing conditions uranium exists in a highly soluble form, U^{6+} (as ion with a positive charge of 6), and is therefore very mobile. However under reducing conditions it converts to an insoluble form, U^{4+}, and is precipitated.

Governing reaction describing of uranium leaching process by sulfuric acid solution in schematic form [1, 2]

$$UO_3 + H_2SO_4 = UO_2SO_4 + H_2O \tag{1}$$

Transfer reaction of useful element from solid phase to liquid phase is produced as

$$\nu_m M + \nu_r R = \nu_p P + \nu_w W \tag{2}$$

where:

M – gram-molecule of mineral (uranium) in solid phase,
R – gram-molecule of reagent (sulfuric acid),
P – gram-molecule of useful element of dissolved uranium,
W – gram-molecule of by-product in liquid phase (ex., water),
$\nu_r, \nu_m, \nu_p, \nu_w$ – stoichiometric coefficient of reagent, mineral, useful element and water, respectively.

The system of equations is considered with following conditions: the medium is homogeneous and isotropic, the density of solution and layer are constant, and solution flow on the layer border doesn't exist. Then these processes are described by following equations using Darcy law and conservation law

$$div\left(K\ grad\ H\right) + \sum_{i=1}^{nw} q_{si}\delta\left(\vec{x} - \vec{x}_i\right) = 0 \tag{3}$$

$$\vec{V} = -K\ grad\ H \tag{4}$$

$$\frac{\partial \overline{C}_m}{\partial t} = -\gamma \varepsilon C_R^0 \overline{C}_m \overline{C}_r \tag{5}$$

$$\frac{\partial \varepsilon \overline{C}_r}{\partial t} = div\left(\varepsilon D\ grad\overline{C}_r - \vec{V}\overline{C}_r\right) - \nu_1 \gamma \varepsilon C_m^0 \overline{C}_m \overline{C}_r -$$
$$-\sum_d q\delta\left(x_d, y_d, z\right)\overline{C}_r + \sum_p q\delta\left(x - x_{0p}, y - y_0, z\right) \tag{6}$$

$$\frac{\partial \varepsilon \bar{C}_p}{\partial t} = div\left(\varepsilon D \ grad \bar{C}_p - \vec{V}\bar{C}_p\right) + \nu_1 \gamma \varepsilon C_m^0 \bar{C}_m \bar{C}_r -$$

$$-\sum_p q\delta\left(x - x_{0p}, y - y_0, z\right)\bar{C}_p$$

(7)

where

$$\bar{C}_m = \frac{C_m}{C_m^0}, \quad \bar{C}_r = \frac{C_r}{C_r^0}, \quad \bar{C}_p = \frac{C_p \nu_1}{C_r^0 \nu_2}$$

$$\nu_1 = \nu_r R / \nu_m M, \quad \nu_2 = \nu_p P / \nu_m M,$$

here:

C_m – concentration of uranium in solid phase,

C_m^0 – initial content of mineral in layer,

C_r – concentration of sulfuric acid in solution,

C_r^0 – concentration of reagent on producing well,

C_p – concentration of useful element (uranium) in solution,

$\vec{V}$ – filtration rate,

q – debit of well ($q_d < 0$ for producing well, $q_p > 0$ for inject well),

ε – porosity of layer,

γ – coefficient, characterizing reaction rate,

$D_{i,j}$ – hydrodynamic dispersion coefficient, defined as:

$$\begin{cases} D_{xx} = \dfrac{\alpha_l u^2}{|V|} + \dfrac{\alpha_t \upsilon^2}{|V|} + D^*, \\[3mm] D_{yy} = \dfrac{\alpha_l \upsilon^2}{|V|} + \dfrac{\alpha_t u^2}{|V|} + D^*, \\[3mm] D_{xy} = \left(\alpha_l - \alpha_t\right)\dfrac{u\upsilon}{|V|} + D^*. \end{cases}$$

(8)

where:

α_L – longitudinal dispersive,
α_T – transverse dispersive.

Equations (5)–(7) are solved at initial and boundary conditions, respectively: mineral distribution in layer is known, concentration of solution and dissolved useful element don't exists at initial time.

$$C_m|_{t=0} = C_m^0, \quad C_r|_{t=0} = C_r^0, \quad C_p|_{t=0} = C_p^0$$

$$C_m|_S = 0, \qquad C_r|_S = 0, \qquad C_p|_S = 0$$

(9)

The differential equation for hydraulic head (3) is solved by over relaxation iterative method. The filtration rate is defined from Darcy law using computed solution of head pressure. And transfer equation of reagent concentration in liquid phase (5), equation of useful element concentration in solid phase (6), and its transition to liquid phase (7) are solved by "Classics" scheme with upstream difference.

The design of ISL well fields varies greatly depending on the local conditions such as permeability, sand thickness, deposit type, ore grade and distribution. The scheme of linear location of well is shown in Figure 2. At this Figure 2 it is seen that the given area could be divided into symmetry blocks (area denoting dotted line). Owing to the symmetry test calculation is realized for block of deposit width 20 m, and length 40 m., consisting of three wells: two injecting and one producing.
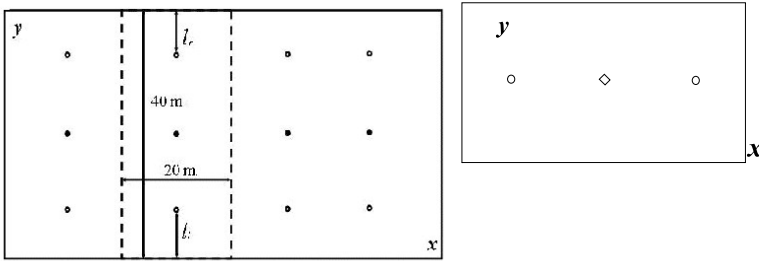

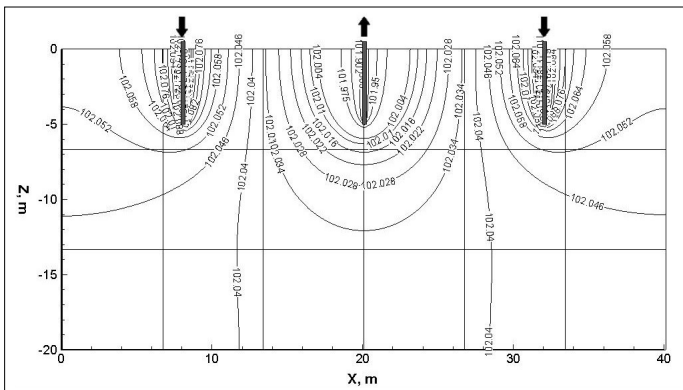**Fig. 2.** Schematic picture of considering area

Fig. 3. Pressure distribution (vertical section along the well)
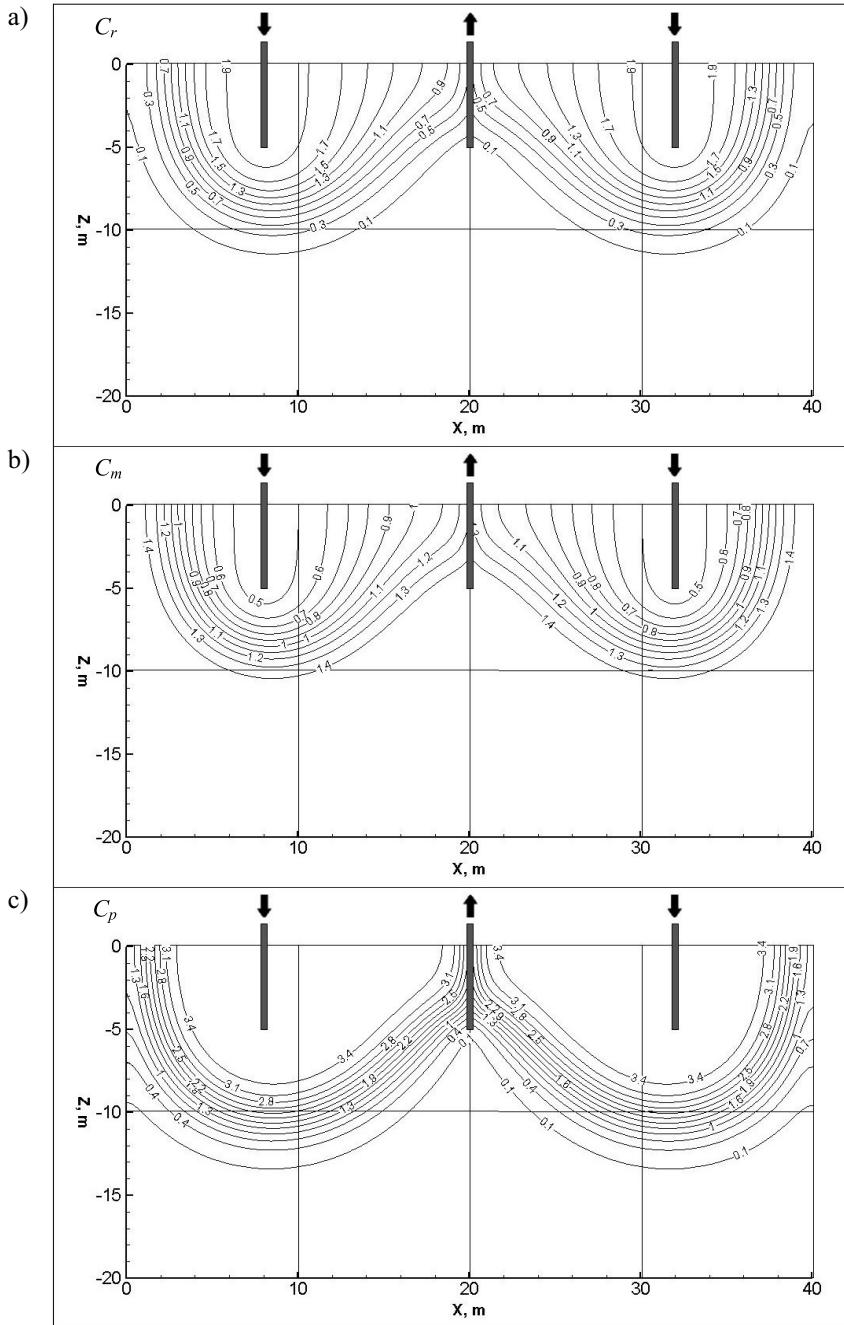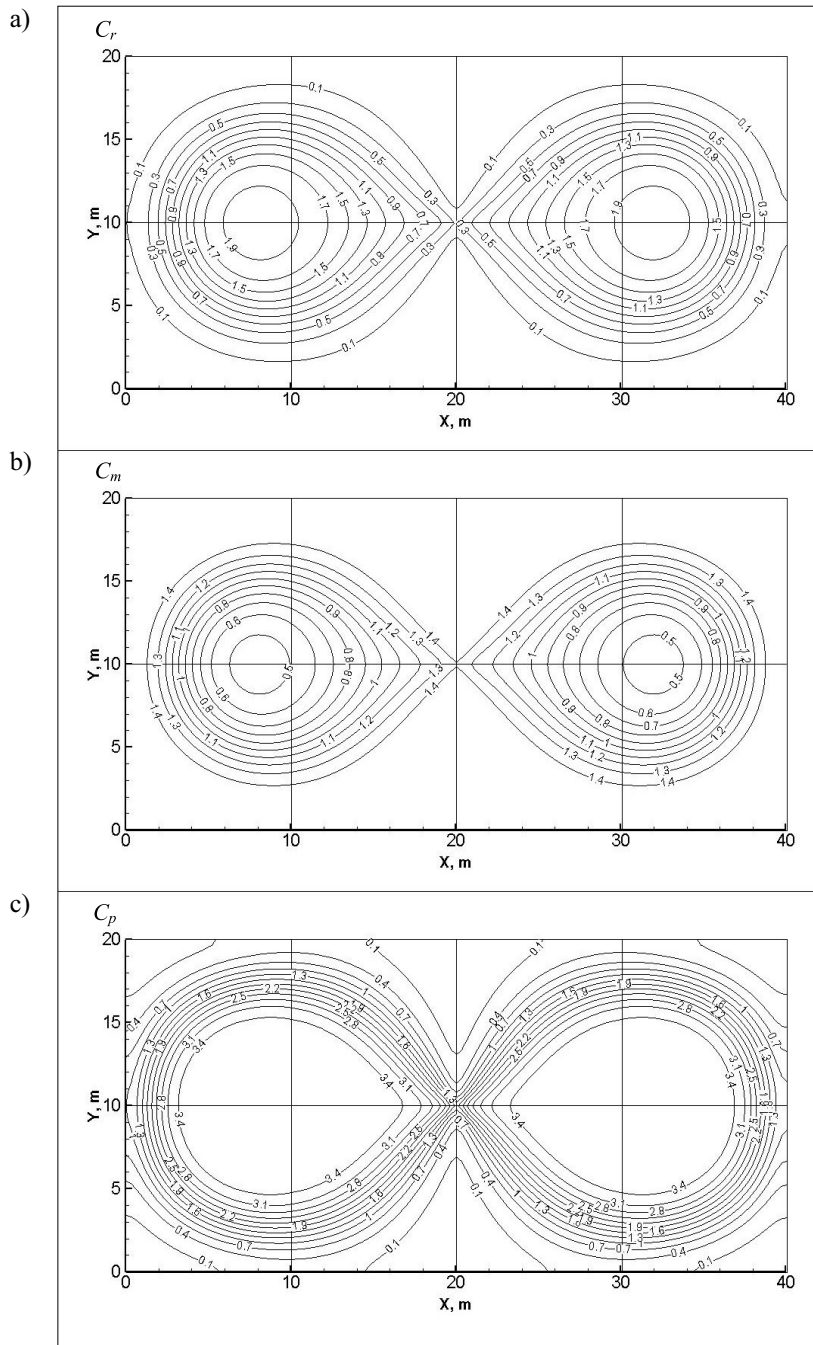
Fig. 4. Concentration isoline: a) reagent; b) useful component in solid phase;
c) useful component in fluid fase, in layer at t = 100 day
(vertical section along the well)

Fig. 5. Concentration isoline: a) reagent; b)useful component in solid phase; c) useful component in fluid phase, in layer at t =100 day (horizontal section on 3 m depth)

Mathematical and numerical models have been considered in this work and computational program for calculation uranium mining process by in-situ leach method is elaborated. Distribution of hydro dynamical pressure, velocity field, distribution of uranium concentration in layer, reagent concentration and useful element concentration in product solution are obtained (Figs. 3–5). The results show that filtration of solution practically doesn't exist in the distance from wells. And so-called stagnant zone is appearing, which brings into decrease of excavation level. ISL can also be applied to other minerals such as copper and gold.

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