Research of hydrodynamic processes in in-situ leaching of uranium

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Abstract. Hydrodynamic processes in the selective transfer of uranium underground to solution were theoretically considered. The effect of the initial filtration gradient on the flow process of underground water flow of weakly permeable and poorly saturated uranium ores by the method of selective transfer of uranium to solution was studied. The hydrodynamic parameters of subsurface selective dissolution of uranium ores with low water saturation were analyzed. The consumption equations and drawings of the injection and production wells by the method of selective transfer of uranium to the solution were developed. Using the consumption equations of the injection and production wells, a calculation program was created in the C++ programming language and the analysis of the obtained results was studied.

1 Introduction

The method of selective leaching underground has a number of advantages over the traditional and expensive methods of mineral extraction. The method of underground selective solution allows to reduce the capital costs for the establishment of enterprises up to 4 times, to reduce the construction time of mines, to increase labor productivity by several times and, accordingly, to reduce the cost of finished products by optimizing jobs. Steady growth in underground uranium mining has averaged 30% over the past decade. Such a rapid increase in the demand for uranium puts before scientists the task of creating unconventional technologies that are theoretically and practically important in production practice. Therefore, it is of particular importance to attract uranium mines with a difficult structure to mining.

Improving the performance of uranium leaching, leaching of low-conducting uranium ores, leaching process and management of various mining systems, low-saturated uranium It is important to create a technology for extracting uranium ore deposits from the ground in places with low pressure of the aquifer.

Today, the process of extracting deep-seated uranium ores by the method of subsurface uranium mining is becoming more complicated every year, and the mining of low-conducting ores with low water saturation by the method of subsurface uranium mining is a problem. is digging. One of the solutions to such problems is to mine low-saturated and poorly permeable

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uranium ores under the control of the hydrodynamic regime, and to use highly activating substances to increase the permeability of the layer.

Mining of underground metals in the technology of selective transfer of uranium from underground to a solution depends on the hydrodynamic mode, which is characterized by the inseparability of the flow in the mode of liquid filtration in the porous volume of the rock massif. The fluid flow rate through the sections (area) of underwater rocks is equal and the movement of fluid between the grains of rocks is difficult.

2 Materials and methods

The purpose of the research is to study the hydrodynamics and consumption of underground water in the method of selective solution underground of poorly permeable and poorly saturated uranium ores.

The method of selective in-situ leaching is a geotechnological method of extracting solid minerals by selectively displacing the useful components of minerals in the place where they lie under the influence of chemical reagents.

Technological wells are underground wells used to carry out the geotechnological process of production.

Injection wells are wells designed to open ore bodies and supply them with working solutions.

Production wells - technological wells designed to open the ore body and release technological solutions (productive, returnable) to the surface of the earth.

Monitoring wells are wells drilled for the purpose of monitoring the level of extraction of useful components from the ores of the productive area, monitoring hydrodynamics, and man-made changes of ore-bearing rocks in the working areas.

Hydrogeological factors such as the water content of deposits and the artesian character of ground water are of great importance in the process of selective solution underground, the reserves and consumption of natural streams, the temperature and chemistry of underground water are of great importance [1-3].

The basis for grouping and dividing deposits into groups is the volumetric relationship between water-permeable ores and rock and the water permeability of the ore. In geological and technological classifications, the comparison of rocks with connections, which was proposed as the main criterion, was replaced by their resistance to water permeability.

Fig. 1. Directional movement of groundwater formed in rock layers.
The property of releasing water through existing cracks and other cavities of rocks is called water permeability. It is determined by filtration (or water permeability coefficient) equal to the rate of water filtration passing through the rock at a pressure gradient equal to one and measured in units of m/day.

The movement or filtration of groundwater in a certain direction in rock layers depends on the difference between the heights of two water flow points and the distance between the points. Filtration can be pressureless or pressurized. Non-pressure filtration is typical for groundwater, pressure filtration for artesian waters.

Let's say that groundwater is moving from point A to point B. Let the height of the water at point A be \( h_1 \), the height at point B be \( h_2 \), and the distance between the points be \( dS \). Then the difference between the points is \( h_1 - h_2 = dh \). In fact, the greater this difference, the greater the speed of groundwater flow. In science, the ratio \( \frac{dh}{ds} \) is called hydraulic slope or hydraulic gradient [3-4].

In the process of pumping groundwater from wells with the help of pumps, the natural level of groundwater (\( H \)) decreases along the sides of the wells. This reduction takes place gradually at the level of \( h, h_1, h_2 \) layers at the radius width \( R \) starting from the location of the well, and the final reduction reaches the initial natural level of groundwater. The curved surface formed as a result of the decrease of the groundwater levels to the level of these \( h, h_1, h_2 \) values is called a depression funnel. The level of underground water before it is pumped out of the well by pumps is static, the level that appears after the water is pumped out of the well is called the dynamic or working level of the well, and the amount of water being pumped out of the well in a certain time unit is called the water consumption or debit of the well.

![Fig. 2. Depression funnel and solution level change in the production well.](image)

According to the law of straight-line filtration, the consumption of water flowing into perfect wells is equal to:

\[
Q = FK_dJ
\]  

(1)

If we take the positions of the points \( y, x \) of the depression funnel in the rectangular coordinate system and draw a cylinder along the ordinate axis from the point \( y \), then the cross-sectional surface of this cylinder is directed towards the well and the ground water at a distance \( x \) from the well axis cross-sectional surface of the flow: equal to

\[
F = 2\pi xy
\]  

(2)
This is the pressure gradient of the flow of water flowing into the well through the face of the section. When

\[ J = \frac{dy}{dx} \]  \hspace{1cm} (3)

\[ Q = 2\pi xy \Phi \frac{dy}{dx} \]  \hspace{1cm} (4)

If we separate the variables in this expression and integrate it in the interval from section I to section II, we get the following:

\[ \frac{Q}{2\pi \kappa \phi} \int_{x_{1}}^{x_{2}} \frac{dx}{x} = \int_{y_{1}}^{y_{2}} y dy \]  \hspace{1cm} (5)

\[ \frac{Q}{2\pi \kappa \phi} \ln \frac{x}{x_{1}} = y_{2}^{2} - y_{1}^{2} \]  \hspace{1cm} (6)

**Fig. 3.** Calculation of the total consumption of the solution in the production well.

The equation is the curvature depression equation in the process of water absorption from a perfect well.

In the equation, \( r \leq x \leq R \) \((r=x_{1})\) (radius of the filter installed in the well), \( x_{2}=R \) (radius of the depression funnel), \( h \leq y \leq H \) \((y=y_{1})\) (height of the water column above the impermeable layer), \( y_{2}=H \) (the height of water calculated from the impermeable layer) is taken, the formula for determining the groundwater consumption flowing into a perfect well is formed:

\[ Q = \pi \kappa \phi \frac{H^{2} - h^{2}}{L_{nr} - L_{nr}} \]  \hspace{1cm} (7)

is the equation for calculating the full consumption of a perfect well.

Taking into account the reduction (decrease) of the water level in the well to the value of \( S \) and \( H^{2} - h^{2} = (2H - S)S \), then the equation

\[ Q_{1} = \pi \kappa \phi \frac{(2H - S)S}{L_{nr} - L_{nr}} \]  \hspace{1cm} (8)

is formed:

\[ Q_{2} = 1.37 \kappa \phi \frac{(2H - S)S}{L_{nr} - L_{nr}} \]  \hspace{1cm} (9)

the equation is the equation for calculating the full flow rate of a perfect well (logarithmic expression of 10) [5-7].

Vertical wells (mining wells) can be used not only for water extraction, but also for pressurized and free water injection. From the point of view of hydraulics, the water absorption of a well is the opposite of the water withdrawal from it. (See Figure 4). Therefore,
the equations that calculate the absorption of wells are similar to the equations of water extraction from a well.

![Injection well](image1)

**Fig. 4.** Injection well.

![Injection pressure well](image2)

**Fig. 5.** Injection pressure well.

Only in these equations, the drop in the water level during the discharge period is replaced by the pressure value $S$ at the water injection. As a result of water injection, the depression formed as a result of draining water from the well creates an overturned appearance of the funnel. While this funnel is realistic for groundwater, it is an imaginary pressure funnel for piezometric water levels for artesian water wells (Figure 5).

The consumption equation of a water pumping well is reminiscent of Dupuy's equation. Only in this case, water is flowing from the well, it is used with a minus sign.

$$Q = -2\pi K \phi \frac{dy}{dx}$$  \hspace{1cm} (10)

If we make a differential equation from this equation:

$$-y dy = \frac{Q}{2\pi K \phi} \frac{dx}{x}$$ \hspace{1cm} (11)
Integrating this equation:

\[-\frac{y^2}{2} = \frac{Q}{2nK_\phi} \ln x + c\] (12)

If we write this equation for sections at distances \(x_1\) and \(x_2\) from the central axis of the well:

\[-\frac{y_1^2}{2} = \frac{Q}{2nK_\phi} \ln x_1 + c\] (13)

\[-\frac{y_2^2}{2} = \frac{Q}{2nK_\phi} \ln x_2 + c\] (14)

If we change the form of equations (4) and (5) and write with respect to \(Q\):

\[Q = \frac{\pi K_\phi (y_2^2 - y_1^2)}{\ln x_2 - \ln x_1}\] (15)

If \(y_1=H\), \(y_2=R\) and \(x_1=r\), then:

\[Q = \frac{\pi K_\phi (h^2 - H^2)}{\ln R - \ln r}\] (16)

If we convert to a logarithm of 10:

\[Q = \frac{1.366K_\phi (h^2 - H^2)}{\lg R - \lg r}\] (17)

In the formula: \(Q\) - water consumption, \(m^3/\text{day}\); \(h\) - aquifer thickness, \(m\); \(h\) - dynamic level, \(m\); \(r\) - well radius, \(m\); \(R\) - radius of influence, \(m\); \(K_\phi\) - filtration coefficient, \(m/\text{day}\). [4-7].

3 Results and discussion

Program for calculation of underground solutions using the Dev-C++ 5.11 program by the method of selective solution of poorly permeable and poorly saturated uranium ores underground:

![Fig. 6. Calculation program.](https://doi.org/10.1051/e3sconf/202452501008)

4 Conclusion

The influence of the initial filtration gradient on the flow process of underground water flow of poorly permeable and poorly saturated uranium ores by the method of selective transfer of uranium to solution was studied. The hydrodynamic parameters of the selective solution underground of uranium ores with low water saturation were analyzed. On the basis of these analyses, mathematical models of the consumption equations of the absorption well with the method of selective transfer of uranium to the solution were developed. Based on the
developed mathematical models, a program for calculating consumption amounts was created in the C++ programming language, and the results were analyzed.

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