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GROUNDWATER CONTAMINATION AND SELF-PURIFICATION AT URANIUM PRODUCTION BY THE IN SITU LEACHING PROCESS

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INTRODUCTION

An important condition of uranium mining industry development is environmental monitoring and ecological security of field development.The well in situ leaching (ISL) method has a less impact on the environment than traditional underground and open-pit mining methods. The uranium extraction is carried out by the technological wells system construction that open a productive horizon containing the ore body. Injection wells are supplied with leaching solutions capable to dissolve selectively uranium containing minerals. The sulfuric acid ISL method is the most widespread in the world. The productive solution is extracted to the surface by the pumping wells and goes into the processing complex for the uranium sorption extraction. Thus, mining is carried out without lifting ore to the surface through selective dissolution of uranium minerals directly in the interior of the earth. At the same time, the deposit development is not accompanied by the formation of overburden and tailing dumps, drainage of underground aquifers, formation of waste waters of hydrometallurgical plants, etc. However, during the field development by the ISL method there is a contamination of underground waters with petrogenic and technogenic substances due to the leach solution injection and its interaction with the host rock [1-3].

To conduct the monitoring of the productive horizon state and to assess the geoecological effects of ISL, it is wise to use mathematical modeling methods. This is due to the process complexity occurring during the ISL and their high inertia, lack of information on the productive horizon state, the high cost of the observation well construction. The report presents a mathematical model of uranium sulfuric acid leaching and software for forecasting the groundwater state during the deposits development by the ISL method. The results of the epigenetic and predictive modeling of the change in the productive horizon state during the development of the Khokhlovsk uranium deposit by the ISL method are presented.

METHODS AND RESULTS

At sulfuric acid ISL, sulfuric acid goes into the productive aquifer together with the working solution. An oxidizer can also be added to the working solution. As a result of the interaction of the leaching solutions with uranium-bearing and rock-forming minerals, a sufficiently large number of different chemical elements pass into the technological solutions. According to their characteristics and ecological significance, all polluting components can be divided into three groups. The first group includes the radionuclides of uranium and thorium series (U-234, U-235, U-238, Th-230, Th-232, Th-228, Ra-228, Ra-226). The second group involves items passing to processing solutions in amounts exceeding permissible limits (Be, Al, Fe, V, Cd, Zn, Pb, Ti, Tl, Ni - 1-3 orders of magnitude, Na, Ca, Mg - several times). The third group consists of elements whose concentration in the technologicalg solution does not exceed the acceptable limits (Co, Mo, Sr, Se, Hg, Ag, Sb, Te, Cu). From the point of view of groundwater pollution monitoring, only the elements in the first two groups are of interest. The movement of polluting components in the aquifer occurs as a result of convective mass transfer, hydrodynamic dispersion and molecular diffusion. In solutions, pollutants migrate in the form of ions, neutral molecules and complex compounds. The form, in which there is a polluting component in the liquid phase, is conditioned by the geochemical conditions. The geochemical situation is determined by the following main factors: hydrogen index pH, oxidation-reduction potential Eh, solution ionic strength, and the presence of a large number of complex agents [4]. In the ISL process, the geochemical state of the productive horizon within the technological units varies significantly. At sulfuric acid ISL, the pH values within the technological unit decreases, and Eh increases compared to the reservoir waters. This can change the oxidation degree of polyvalent elements, such as iron and uranium, as a result their migration properties are changed. Contaminants can be also in the form of complex compounds. The main ligand at sulfuric acid leaching is sulfate ion. In the form of complex compounds, the components can increase their migratory ability or form sulfate insoluble compounds. It is not possible to describe the migration of all components of the ISL process in details. Therefore, when creating a model, it is necessary to determine the main physical and chemical processes to choose a limited number of minerals, components, the descriptions of which are sufficient for adequate modeling of the pollutants migration.

In this paper we present a model describing the main hydrodynamic processes and physical and chemical processes that determine the pollutants behavior in uranium sulfuric acid ISL [5]. Among hydrodynamic processes are filtration of solutions within porous medium and hydrodynamic dispersion. Physical and chemical processes include complexation, diffusion, homophase and heterophase oxidation-reduction and acid-base processes, sorption, mineral precipitation-dissolution, solution components coprecipitation. The following components contained in technological solutions in significant quantities and determining the geochemical environment - Fe^{3+}, Fe^{2+}, Al^{3+}, Ca^{2+}, H^{+}, OH^{-}, K^{+}, Na^{+}, Mg^{2+}, S^{2-}, SO_4^{2-} are considered in the model as well as radioactive contaminants (U^{4+}, UO_2^{2+}, Ra^{2+}, Th^{4+}). The model does not examine the components of the third group as they are contained in the ISL process in a small amount and do not affect the geochemical situation. Also, some of the elements of the second group contained in a small amount in technological solutions are not taken into consideration. This is due to the fact that they precipitate in the form of hydroxides during acid neutralization as a result of interaction with the host rock and don't extend beyond technological units.

Based on the created mathematical model, problem-oriented software was developed to predict the pollutants migration within underground water and the effect evaluation on the environment as a result of uranium mining by the ISL method [6]. The software allows to carry out calculations taking into account actual operating modes of technological wells, working solution compositions, hydrogeological structure of productive horizon and regional groundwater flow. The software is developed in C ++ programming language and intended for the use on personal computers (PC) with Microsoft Window XP-10 operating systems. Interaction with geological and technological databases is carried out through SQL inquiries.

DISCUSSION AND CONCLUSIONS

Groundwater contamination and self-purification of the productive horizon after the uranium mining is considered on the example of the central part of the Khokhlovsk uranium deposit. Khokhlovsk deposit belongs to the Zauralsk uranium ore region. The deposit development is carried out by Dalur, which is a part of the ARMZ uranium holding. The simulation was carried out on the basis of the deposit hydrogeological model constructed with the help of a mining and geological information system based on the data of exploration and technological wells geophysical investigation [7]. The information on working solution compositions and technological well operating modes was imported from the technological database of the mining complex information system [7]. Epigonous simulations have been carried out since the beginning of operation up to the present but forecast calculations for a twenty-year period after the uranium mining completion.

The simulation results show that having started the operation, the acid content in the technological solutions within the operating unit region increases. After attaining a value of several grams per liter less then acid concentration in the leaching solutions, the acid content is terminated. Similarly, the oxidation and reduction potential Eh which values increase from 100-200 mV to 350-450 mV during the ISL process, behaves. The total iron content also increases during ISL process reaching values about of 1 g/l. The uranium content in the technological solutions increases, reaches the maximum values and decreases as the ore body is worked out. The ion sulfate content in the process solutions of the operating unit is increased by reaching values of 15-20 g/l to the mining completion. The contents of aluminum, potassium, sodium, magnesium are increased as well. Thus, the total mineralization of technological solutions increases to 30-40 g/l. During ISL process, most of the technological solutions remain within the operating unit region. This is due to the rates equality of the working solution injection and productive solution pumping out both for separate operational unit and the entire field. When the process solutions leave the operating unit region, the acid neutralization and formation of uranium and other pollutants insoluble compounds take place. As a result, the area of uranium distribution goes beyond the outline of the technological units for distances not exceeding 20-30 meters. The sulphate ion having the highest migration capacity extends beyond the block outline for the maximum distances of 80-100 meters. To confirm the adequacy of the ISL process description by the created model, the simulated and actual time dependences of the uranium concentration, two and trivalent iron, sulfuric acid and sulfate ion in productive solutions were compared. The comparison was carried out both for individual pumping and observation wells, and for operational unit and the entire field. A good coincidence of simulation results with real data confirms the adequacy of the proposed model and the correctness of the software operation.

Having completed the field development neutralization of the acid and increase in the pH of the residual process solutions have been occuring for several years due to the interaction with the host rock. As a result, insoluble hydroxides of uranium, iron, aluminum are formed and their concentration in residual solutions decreases. At the same time, insoluble sulphate containing minerals (gypsum, alunite, jarosite, etc.) are formed. For 20 years the total mineralization of residual technological solutions has decreased from 30-40 g/l to 7-10 g/l. Having completed the operation, the lens of residual solutions remains within the operating unit region as a result of the very low rate of groundwater regional movement in the productive horizon of the Khokhlovsk uranium deposit.

The simulation results show that in the case of uranium ISL, the groundwater contamination region is local and situated mainly within the boundaries of the operational units. The main indicator of pollution is sulphate ion because its content in processing solutions with sulfuric acid ISL much more exceeds the concentrations of other components, and it has high migration ability. According to its distribution in the underground waters it is possible to evaluate the area of the productive horizon pollution. Having completed the uranium mining, there is self-cleaning of the productive horizon in some decades. The pollutant concentration reduction occurs in the result of the interaction of residual technological solutions with rock-forming minerals, formation of new minerals and dilution with groundwater waters. The self-cleaning process speed depends on the mineralogical composition of the ore-bearing rocks of the productive horizon and the intensity of water exchange. In the case of a low groundwater movement speed, the self-cleaning process takes place within a region slightly beyond the boundaries of technological units.

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