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Development of Mathematical Models to Control the Underground Leaching Process

Ismanova Klara Dulanboevna , Ph.D.
Namangan Institute of Engineering and Technology
Namangan, Uzbekistan

Abstract : The article analyzes the physical and chemical foundations of the in-situ leaching process, data processing using approximate analytical solutions to predict the required parameters and verify the reliability of the developed process control model, and conduct a system analysis of the in-situ leaching process as an object of study.

Key words: *Underground teaching, the useful component, the concentration, system analysis, criterion of optimization .*

Underground leaching is a physical and chemical process of extracting minerals (metals and their salts) by washing them out of the rock with various solvents injected into the deposit through wells .

In-situ leaching is an alternative to open pit and underground mining methods. Compared to them, in-situ leaching does not require a large amount of excavation or direct contact of workers with rocks at their location. Effective even in poor deposits, as well as for deep-seated ores.

The process starts with the drilling of wells, explosives or hydraulic fracturing may also be used to facilitate the penetration of the solution into the deposit. After that, a solvent (leaching agent) is pumped into the well through a group of injection wells, where it combines with the ore . The mixture containing dissolved ore is then pumped through pumping wells to the surface, where it undergoes extraction .

In-situ leaching by their structure are complex technical multi-connected systems covering several subsystems (reservoir-well - pumping stations - concentrations of reagents, etc.). All these subsystems are interconnected, and violation of the technological regime of at least one of the subsystems leads to a stop of the entire cycle of the system as a whole. Therefore, at present, much attention is paid to progressive methods for the development of multicomponent systems, one of which is the method of in-situ leaching (IL). The PV method is the most economical and harmless in comparison with other methods, and its use does not lead to environmental damage.

The dissolution of a useful component in the bowels of the earth and the subsequent movement of the formed compounds occur mainly in accordance with the laws of hydrodynamics, the laws of mass transfer and chemical kinetics. The complexity of the process occurring in real underground conditions necessitates the development of mathematical models and software to study the entire cycle of the HP process in real conditions and make decisions in accordance with the control goal. The main purpose of creating a model is the characterization and prediction of some objects and technological processes. Models based on the mathematical interpretation of the problem help in finding the necessary information for making decisions using certain algorithms. A mathematical control model for decision-making in the analysis of the technological process of HP is proposed in the following equation, which reflects the nature of the change in the filtration flow:

$$\frac{\partial}{\partial x}\left(\frac{kh}{\mu}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{kh}{\mu}\frac{\partial H}{\partial y}\right)+\mu\sum_{i=1}^{N}\delta(x-x_i,y-y_i)Q_i(t)=mh\beta\frac{\partial H}{\partial t} \quad (1)$$

in the region $G=\{(x,y,t)/\ a<x<b,\quad c<y<d,\quad 0<t\le T_k\}$ satisfying the boundary $(\alpha\frac{\partial H}{\partial n}+(1-\alpha)H)/_{\Gamma}=\varphi(x,y)$ and initial $H(x,y,0)=H_0(x,y)$ conditions.

After solving problem (1) and determining the pressure *H, the filtration rate* is found according to the Darcy law: $v_x=-k_1\frac{\partial H}{\partial x}$, $v_y=-k_2\frac{\partial H}{\partial y}$.

In order to determine the concentration of a useful component in the reservoir, the equation of convective diffusion is considered:

$$\frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D\frac{\partial C}{\partial y}\right)-\frac{\partial(v_xC)}{\partial x}-\frac{\partial(v_yC)}{\partial y}-\gamma(C-C_m)=m\frac{\partial C}{\partial t},$$

(2)

$$\frac{\partial N}{\partial t}=\gamma(C)f(C,N,L,\Gamma),\quad N(x,y,0)=N_0(x,y)$$

in the domain G with initial $C(x,y,0)=C_0$ and boundary $(\alpha\frac{\partial C}{\partial n}+(1-\alpha)C)\Big|_{\Gamma}=\psi(x,y,t)$, as well as internal $C(x,y,t)\big|_{(x,y)=(x_i,y_i)}=C_i$, $\frac{\partial C}{\partial n}\Big|_{(x,y)=(x_j,y_j)}=0$ conditions.

The main task is to ensure appropriate actions through the control of the IW process and the choice of parameters that guarantee the implementation of the following main goals: minimizing the influx of the reagent through the ore-bearing boundaries of the formation; ensuring uniform hydrodynamic leaching; maximizing the concentration values of the useful component; optimal location of wells.

These goals are realized by minimizing the objective function R by choosing the optimization criterion (U), i.e. problem solving

$$R(U)=\int_0^T\sum_{i=1}^{N_t}[C_i(X,U)-C_{ib}(X,U)]^2dt,\ \ R^*=\min_{U\in\Omega}R(U),\quad R(U^*)<\varepsilon,\ \ U_0<U<U_n,\ \ \Omega=\{\gamma,q_o,q_\kappa\}$$

Here $C(X,U)$ is the solution of problem (1)-(2) at the point (x , y) at a given time t, $C_b(X,U)$ is the required optimal value of the useful component, ε is the given accuracy, U is a vector with components, γ is the acid concentration in the injected solution, q_o, q_k – well flow rates, v – filtration rate , etc. The following control criteria are introduced to solve this problem.

Usually in control systems it is impossible to immediately influence the control object and its evaluation. They are evaluated some time after exposure. And be sure to include feedback and a process of correction. This can be depicted using the main control components (Fig. 1).

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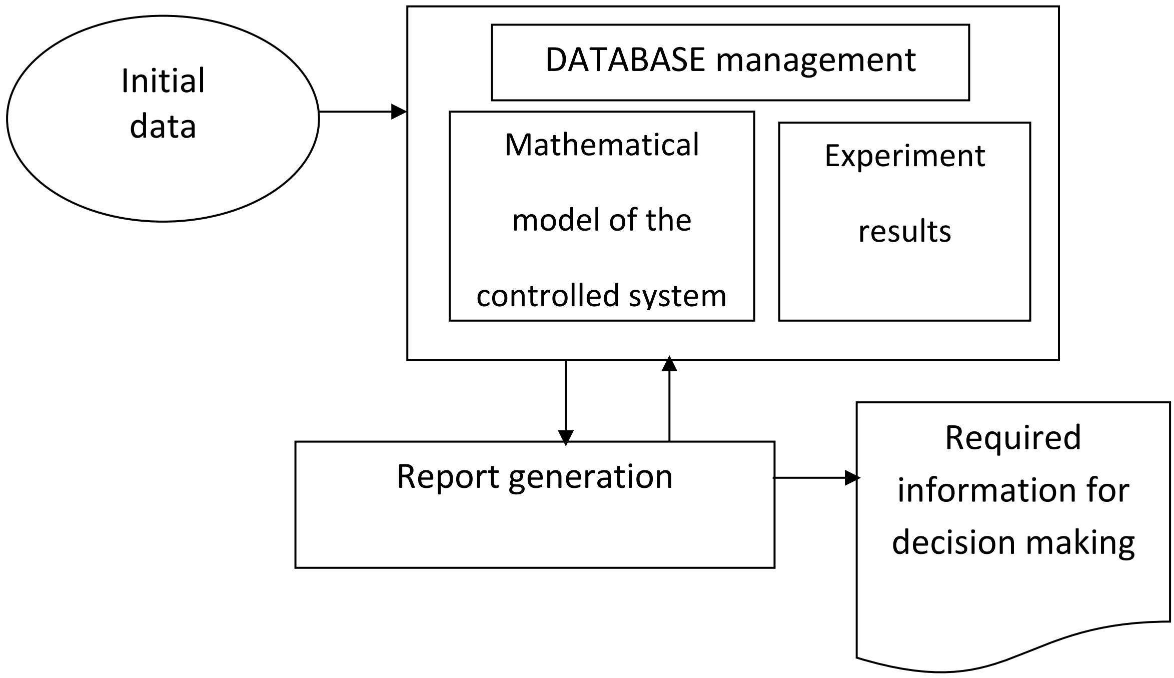
Fig. 1. Main control components



Here, as the initial data, information about various input parameters of the mathematical model for controlling the technological process of HP based on the decision is used. By solving the models listed above, we study the impact of parameters on the physical process and, as a result, we obtain a certain database of decision-making to achieve the goal. The software created by us allows expanding and replenishing the above database.

Usually, first, division into blocks of an arbitrary deposit, which is developed using the method, taking into account its known features, takes place, and a separate development is subsequently approved.

Due to the complexity of the PV process, the selection of parameters does not occur simultaneously, but separately. Hydrodynamic parameters are selected using a hydrodynamic model for the IW process. As experimental values, dynamic quantities used in the previous development are used. After that, the kinetic parameters are chosen. In this case, the output parameters or the final goal is to maximize the concentration values of the production well.

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