Proceedings of ALGORITMY 2002
Conference on Scientific Computing, pp. 207–214

THE METHODOLOGY OF THE GEO-TECHNOLOGICAL PROCESSES CONTROL PARAMETERS' SELECTION

J. NOVÁK AND H. ČERMÁKOVÁ*

Abstract. The geo-technological methods are used during the mineral mining, the collector remediation and engineer activities, which require the underground encroachments. These methods do not use nor the deep-mined nor the open-cut works in general.

One of the largest application in the Czech Republic has been represented by the uranium mining on the Stráž deposit in the Northern Bohemia. During the chemical mining the deposit has been opened by the bore holes system, through which the leaching solution has been injected into the underground and the enriched leaching product has been drawn in the ground chemical station and after the adding of the reduction reagents the solution has been injected again.

1. Introduction. There are two main factors influencing the leaching course - the leaching ability and the ore permeability. Fig. 1.1 shows the leaching test results of the middle leachable ore specimen from the Stráž deposit. On Fig. 1.1 we can see the strong yield dependence on the sulphuric acid concentration in the leaching solution.

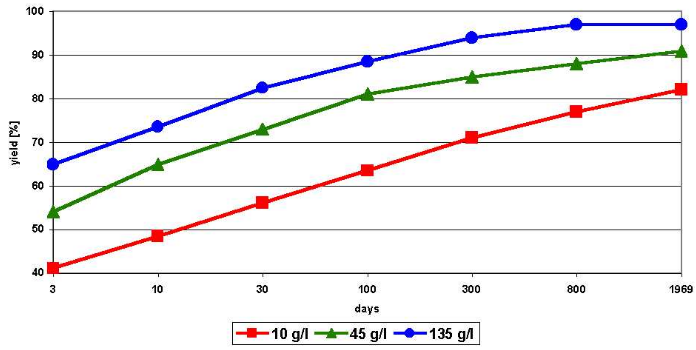

FIG. 1.1. *Uranium leaching kinetics depending on sulphuric acid concentration.*

The leaching regime represents the time schedule of the leaching reagent dosing and the circulation intensity. First the acid dose is higher, later it decreases to the zero level, which means the only acid contained in the mining solution comes back into the deposit without any other addition. This procedure corresponds to the higher reactive consumption of acid during the first contact of the rock with the leaching solution and the necessity of reaching the required acid concentration in the deposit.

For the same reasons the solution circulation intensity is higher during the initial time period of the chemical mining. The solution fills faster all the pores of the ore deposit and it helps to accelerate the leaching process start.

*Technical University of Liberec, Dept. of modelling of processes, Hálkova 6, 461 17 Liberec

2. The uranium leaching kinematics and the acid consumption. The reaction course of one mineral grain can be described by

$$\eta = 1 - e^{-K a^n t} \tag{2.1}$$

where:

- η is the yield ,
- a the acid concentration in the solution,
- K the reaction speed coefficient,
- n the dependence of the reaction intensity on the acid concentration,
- t time.

This equation is applied not only for the ore minerals but also for the rock components, which react with the acid. The acid concentration is reduced by the reaction with the rock. But in the given point the acid concentration also changes depending on the motion of the solution contained non-reacted acid. Then we can modify the equation (2.1) as follows:

$$\eta = 1 - e^{-K \int_0^t a^n dt}. \tag{2.2}$$

The substance concentration change in the elementary rock volume is described by the equation:

$$\frac{\partial q}{\partial t} = -K\, a^n\, q \tag{2.3}$$

where: q is the current substance concentration in the rock.

The uranium and the acid concentration change in the pore solution are the partial change's sum, which are elicited by the individual mineral components. It applies:

$$\gamma_r \frac{\partial c}{\partial t} = \pm \frac{1-\varepsilon}{\varepsilon}\, \gamma \sum K_i a^{n_i} q_i \tag{2.4}$$

where:

- c is the substance concentration in the solution (the uranium or the acid),
- ε the porosity,
- γ_r the solution density ,
- γ the rock density,
- a the current acid concentration,
- q_i the current concentration of the $i-th$ mineral component in the rock,
- $+$ applied for the uranium, which during decreasing in the rock increases in the solution,
- $-$ applied for the acid, which during the decreasing of the ballast substances in the rock decreases in the solution.

The technology solution and the rock environment represent multi-component system with difficult intro-phase and inter-phase substances changes. The uranium ore mineralization is connected with various mineral forms with the different leachabilities and besides it occurs in the various rock types, whose minerals are "acid consumers". We use the equation (2.2) for each rock component with the relevant parameters values. For the practical calculations the time discretization is put in the equation

(2.2), which responds the real step of the operation monitoring (one month). The quantity of the leached uranium or the reacted acid Q in the defined volume we can determine by the equation using:

$$Q = \sum_i D_i \left(1 - e^{-\sum_j K_i a_j^{n_i} \Delta t}\right) \tag{2.5}$$

where:

- i is the index of the ore mineralization component or the reacted rock component,
- j the time step index,
- D_i the uranium quantity in the ore mineralization of the i-th component in the given rock volume in time t = 0, or the reacted acid quantity equivalent in the i-th reacting component,
- K_i the velocity reaction coefficient of the i-th component,
- n_i the i-th component reaction intensity dependence on the acid concentration,
- a_j the acid concentration in the inspected rock volume in the time period j,
- Δt the calculation time step.

3. The leaching block relations. The acid concentration and the reacted substances concentration in the rock are different in every point of the interest area in general. Therefore the equations (3.1) - (3.4) apply only for the same elementary rock volume. The general result is obtained by the numerical integration over the solved area, which is variant according to the used transport model type.

The simplified volume model (Novák, Štrosová 1984) was developed for the leaching results operative prognosis. In this model the flow (fulfilling of the interest area) was approximated by the equation (3.1) based on the detail results of the flow models

$$R(t) = 1 - e^{-\frac{I}{V_0}} \tag{3.1}$$

where:

- R is the modelled area volume of the mining block, which is fulfilled by the solution in time t,
- I the solution circulation intensity,
- V_0 the pore space volume in the interest area.

The reaction of the solution and the rock is not starting simultaneously in whole area. If there is a homogenous environment in the mining block, we can suppose the increase of R in short time interval to be a volume of rock with uniform concentration of reacting substances and the acid, where the relations (3.3, 3.4) are applied. The integration can substitute the sums of the increase R partial volumes in the individual time intervals and over intervals Δt in space volumes, since their reinforcement by the solution.

Under ideal condition, during state circulation and ideal solution mixing, the solution's substance concentration change in the block's of interest pore space is described by differential equation:

$$\frac{dc}{dt} = \frac{I}{V_0}(c^V - c) \pm \frac{1}{V_0} \cdot \frac{dQ}{dt} \tag{3.2}$$

where:

c is the solution's substance concentration in the block pore volume,
V_0 the block volume,
c^V the substance concentration in the impacted solution ,
Q the substance quantity leached from the rock (+) or reacted in the rock (-),
t the time.

If the expression dQ/dt is replaced by the substance quantity change ΔQ in time interval Δt, then the equation has the solution:

$$c = c_0\, e^{\frac{I.t}{V_0}} + \left(c^V \pm \frac{\Delta Q}{I\,\Delta t}\right)\left(1 - e^{-\frac{I.t}{V_0}}\right) \tag{3.3}$$

where: c_0 is the initial substance concentration in the solution.

Practically the conditions are different from the ideal state. Intensities of drawing and injection are not the same in particular periods, in consequence an overflow of the solutions between the leaching fields exists. Therefore the corrections of the unbalance between the solution injecting and the solution drawing are adopted in the equation (3.3).

$$\begin{aligned} c_i = {} & c_{i-1} \cdot e^{-\frac{I_i^T}{V_0}(t-t_{i-1})} \\ & + \left[I_i^V \cdot c_i^V + (I_i^T - I_i^V)\, c_i^P \pm \frac{\Delta\, Q_i}{\Delta t_i} \right] \cdot \frac{1}{I_i^T}\, (1 - e^{-\frac{I_i^T}{V_0}(t-t_i)}) \end{aligned} \tag{3.4}$$

for $t_{i-1} < t \leq t_i$ where:

I^T, I^V is the mining intensity and the injecting solution intensity,
$i = 1, 2...$ the time period index,
c^P the substance concentration in the volume transferred across the field boundary.

4. The basic economical relations of the chemical mining. The field regime optimization is necessary run not only according to the technology but also to the economic criteria. The unit costs are used for the regime effectiveness evaluation, which we obtain by the dividing the global variable costs by the uranium production in the relevant time period.

The immediate unit costs (= marginal costs – M) characterize the current operation in the sufficient short time period. The average unit costs (U_A) in the whole period contains the leaching field construction costs.

Fig. 4.1 shows the designed course of both unit cost types. The start of the production development is quick, therefore the immediate unit costs are low. Then they are rapidly increased in consequence of the uranium production decrease.

The average costs are gradually decreased with the increasing production until time moment t_1, when the average costs decreases to the lowest level. Therefore the field operation would not be finished before time t_1.

The limit costs (L) level is described in the picture. The limit costs are the immediate unit costs, when it is possible to mine. The immediate unit costs line intersects the limit costs line in time t_2. This is moment, when it is necessary to finish mining for the economic reasons.

The criterion of the regime selection is the criterial profit (K), which is defined:

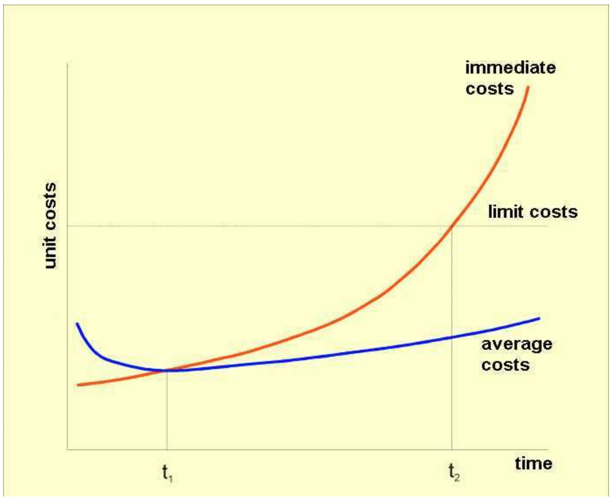

FIG. 4.1. *Determining of the effective mining period.*

$$K = P \cdot L - N = \sum_i P_i(L - M_i) - N_p \tag{4.1}$$

where:

- P is the total uranium production since the mining has been started,
- P_i the production in the i-th period,
- L are the limit costs,
- N the total variable costs since the mining has been started including the field construction,
- N_p the mine preparation costs (the field construction, the pre-acidity),
- M_i the variable unit costs in the i-th period.

5. The optimization model. The optimization model is the superstructure of the underground processes model. This superstructure provides the feedback of the model output signals and the model inputs. If one of the watching variables values deflects from the demanded interval, the input modification is performed and the current time step calculation is repeated.

The whole system has to react on the immediate unit costs increasing with the sufficient lead time. The active phase (the acid proportioning) has to be finished sooner than the immediate unit costs approach the limit costs.

The basic schedule of the model activity is shown on Fig. 5.1.

The limit costs (L), the circulation intensity maximum, which the bore holes mesh admits (I_{MAX}) and finish (limit) acid concentration in the underground (C) are set out in the input data. The initial acid portion (K) can be arbitrary because it is modified by the model in every step.

The underground processes module counts the leaching products quality, the uranium production in the period and the also the underground situation. The relevant output for the optimization model activity is the acid concentration in the underground. It is compared with the given finish concentration C. If the condition (5.1) is not fulfilled

$$C.(1 - A) < c < C.(1 + A) \tag{5.1}$$

where:

c is the acid concentration in the underground,

A the limit of the tolerated departure.

then the acid portion K are either increased or decreased and the calculation for the given time period is repeated with the corrected acid portion according to necessity in several iterative steps. The acid proportioning can decrease short-term to the zero level, if the acidity is sufficient.

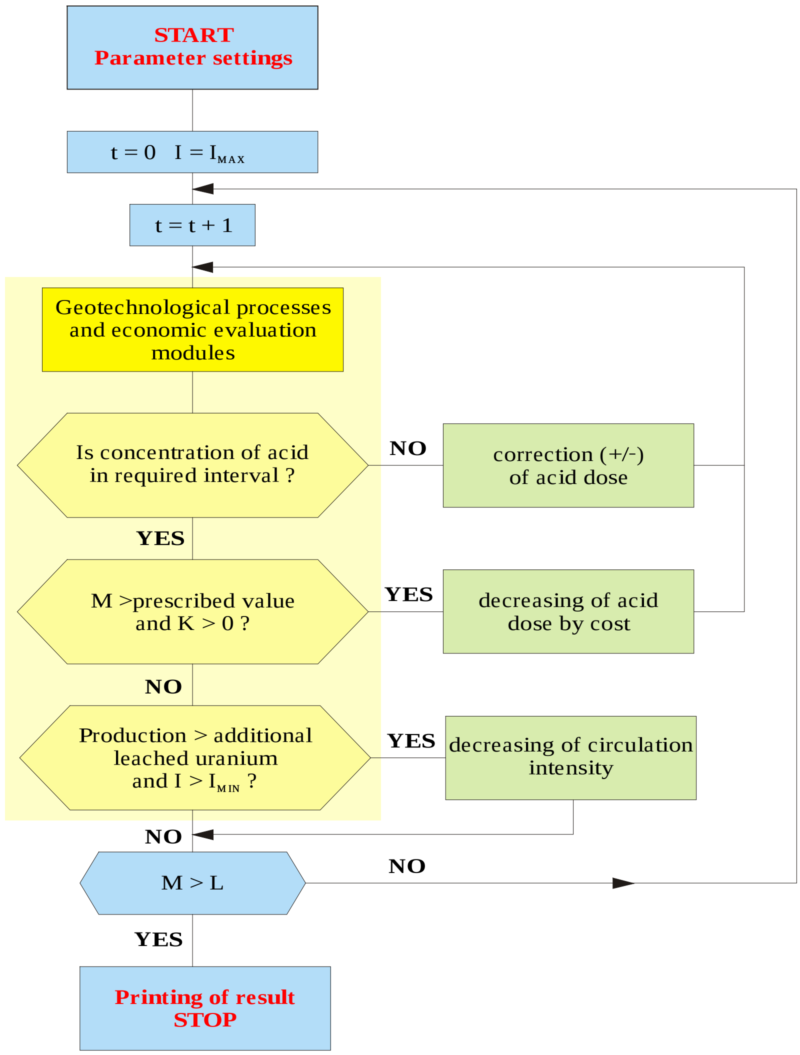

FIG. 5.1. *The model for the optimal regime finding of the leaching active phase*

If the condition (5.1) is fulfilled, the calculation further comes on the economic evaluation. The relevant output is the immediate unit costs value. If the acid portion is not equal to the zero value, the condition (5.2) is tested:

$$M - L.D < 0 \tag{5.2}$$

The coefficient $D < 0$ is used with regards to the underground processes inertia so as all the acid would be purposely used. If the condition (5.2) is fulfilled, the acid portion is reduced by the quantity, which price corresponds the absolute value of the left side of the expression (5.2)

$$K_{kor} = K + \frac{(M - L.D)}{H} \cdot P \tag{5.3}$$

where:

K_{kor} is the corrected (decreased) acid portion,
H the acid price [crowns per ton],
P the uranium production in the time period.

The calculation of the given time period is repeated with the corrected portion. If the acid portion is reduced to the zero level, the acid proportioning is finally stopped.

Regulation of acid doses Regulation of circulation intensity

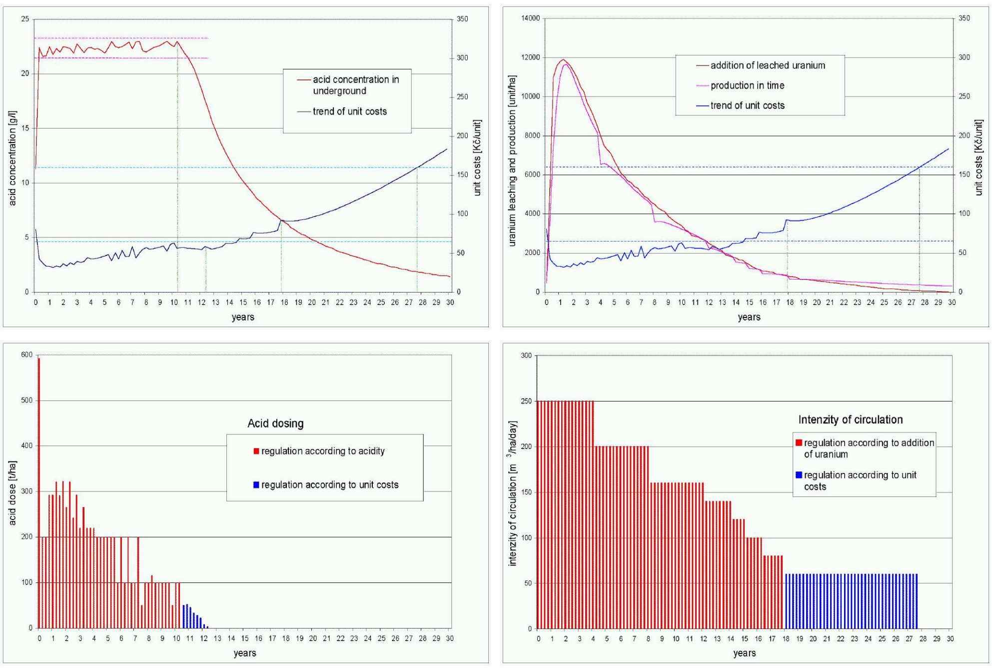

FIG. 5.2. *Control of the leaching field operation regime according to the optimization model.*

The test of the circulation intensity evaluation is performed independently on the acid portion. If the uranium production is higher than the additionally leached quantity in the given time period, the intensity is decreased in the rated ratio. By this the production is reduced and the mined concentration fall is slowed down. If the intensity reaches the given minimum value IMIN, further reducing is not performed. The reduction is applied to the next time step.

Then it is tested, if the immediate unit costs do not overstep the limit costs level. If not, the calculation comes on the next time step, else the calculation is stopped.

The sample of the controlled process course is shown on the Fig. 5.2.

First the acid concentration is kept on the optimal level, later on the acid portion is reduced to the zero level in accordance to economic criteria. Together the circulation intensity is decreased to the minimum value and the mining is finished because of the non-acceptable immediate unit costs arise.

Besides mentioned model, another model versions of the field regime optimization were developed.

6. The conclusion. The underground process control represents the complicated problem. It is necessary to determine the optimal acid proportioning and the circulation intensity during the uranium leaching so the exploitation effect would be maximal. Further it is necessary to develop the process simulation model, which accepts often extremely different characteristic features of the concrete deposit parts and describes the underground's reaction on the technology intervention.

The optimization model is the superstructure of the simulation model. Not only technological parameters but the process costs are regarded and evaluated its effect according to the maximum profit criteria.

REFERENCES

[1] Novák J., Mareček P. and Smetana R.: *Modelling of the ISL in the Stráž deposit,* Proceedings of the Technical Committee Meeting IAEA on Computer Application in Uranium Exploration, Vienna, Austria, 1994.

[2] Novák J. and Smetana R: *Determination of U reserve area suitable for ISL mining,* Proceedings of the International Conference UREX-96, Beijing, China, 1996.

[3] ———: *The economic limits of the ISL mining,* Proceedings of the Technical Committee Meeting IAEA on In Situ Leach Uranium Mining, Almaty, Kazakhstan, 1996.