Acoustic Stimulation on Underground Leaching

D. A. Kas'yanov and G. M. Shalashov

Radiophysical Research Institute,
Russia, 603950, Nizhny Novgorod, B. Pecherskaya, 25;
E-mail: kasd@nirfi.sci-nnov.ru

Abstract. Report presents the experience on acoustic intensification of underground leaching (UL) of less-common metals. In experiments the extended downhole antennas with a possibility of acoustic field focusing were used. It is experimentally shown that elastic vibrations can considerably intensify the substantial process of UL, it is possible to receive rather continuous effect of intensification, using short-lived impact.

INTRODUCTION

It seems unreasonable that less attention has been paid to development of methods for acoustic-field stimulation of underground leaching (UL), although the share of such geotechnological methods of mining in the total worldwide extraction of mineral and raw material resources constantly increases [1]. This is caused by the necessity of using low-quality raw materials that earlier were considered unprofitable for mining, since rich-ore deposits go dead while the demand for mineral resources constantly increases. Moreover, ecologically, UL processes are more attractive than cut or underground mines.

To date, it is worldwide practice on industrial scale to use underground smelting of sulfur, borehole hydraulic mining of phosphorites, leaching of salts of radioactive elements, nickel, copper, molybdenum, tungsten, arsenic, mercuric ores (underground annealing), gold, etc. [2 - 4].

Each UL technology must be extremely complex to meet the requirements of a particular deposit, since each deposit has its own geology, hydrology, physico-chemistry, and so on. To our knowledge, none of the existing UL technologies use acoustic stimulation. Conventionally, underground leaching includes the following stages: bringing reagents to the raw material to be solved, solution, diffusion, and filtering of enriched solution for the mining collector. Certainly, each stage is an object of acoustic intensification. The possibility of intensifying reagent pumping processes and their further filtering affected by an acoustic field was proved by not only laboratory but even pilot-industrial experiments in the oil industry [5, 6]. Of course, the rocks subject to UL can have a considerably smaller penetrability than oil-carrying strata (e.g., ore bodies). Then acoustic fields need to be focused for provision of the maximum increase in amplitude of the stimulating acoustic field. As concerns intensification of solution processes under the action of an acoustic field, there is a large number of experimental data [7 - 12] confirming that an acoustic field has a considerable effect on chemical processes including hydrometallurgic geotechnologies.

However, it should be mentioned again that such an effect on physical and chemical processes has a threshold with respect to the acoustic-field intensity [7, 8, 11, and 13]. Thus, the problem of a tool, i.e., the problem of a borehole antenna, is no less important for acoustic stimulation of UL processes than for oil-mining intensification. Antennas with focusing of cylindrically divergent waves, designed as, e.g., in [14, 15], have the maximum capabilities for the creation of an intense acoustic field at near-hole area of borehole.

In what follows we describe the pilot semi-industrial experiment on acoustic stimulation of UL of less-common metals with the use of focusing borehole antennas (Nizhny Novgorod Radiophysical Reserach Institute - Navoi Mining Metallurgic Plant, 1988 - 1991).

On industrial scale, the method of UL of less-common metals has been successfully used since the sixties in the last century and has found most extensive use in the so-called hydrogenic deposits. The formation of such deposits is associated with the deposition of a metal from oxygen ground waters at the reduction-oxidation barrier originating due to motion of these waters over permeable strata. Mining of such a deposit by the leaching method is essentially a process that is inverse of the natural one. The metal deposited earlier is transformed to a mobile ion form, changing the chemical composition of stratum waters. For this, a lot of injecting and exhaust wells are located in bed surroundings. Leaching reagent is injected in productive bed and is dissolved in stratum waters. Then active solutions are filtered in the productive stratum, are enriched by useful components, and are extracted through exhaust wells. Underground leaching is a typical example of a heterogeneous chemical reaction limited by the diffusion resistance in one phase. The influence of elastic vibrations on similar processes is common knowledge but needs to be studied better [7, 16].

EXPERIMENTS

Field Testing

An object of stimulation in the described experiment was the near-hole area of one of the exhaust wells. Figure 1 shows location of testing well on the UL field. Figure 2, 3 show exhaust well gallery cut and injecting well gallery cut respectively. As the acoustic radiators, we used extended focusing borehole antennas, designed as zone lenses [17]. The stimulation was performed from the filter zone of an exhaust well, and the filter was located in the region of the productive collector of the stratum being mined. The borehole used for the experiments was put into service in January 1989. The washing, pumping, and treatment by pneumatic pulses were not performed

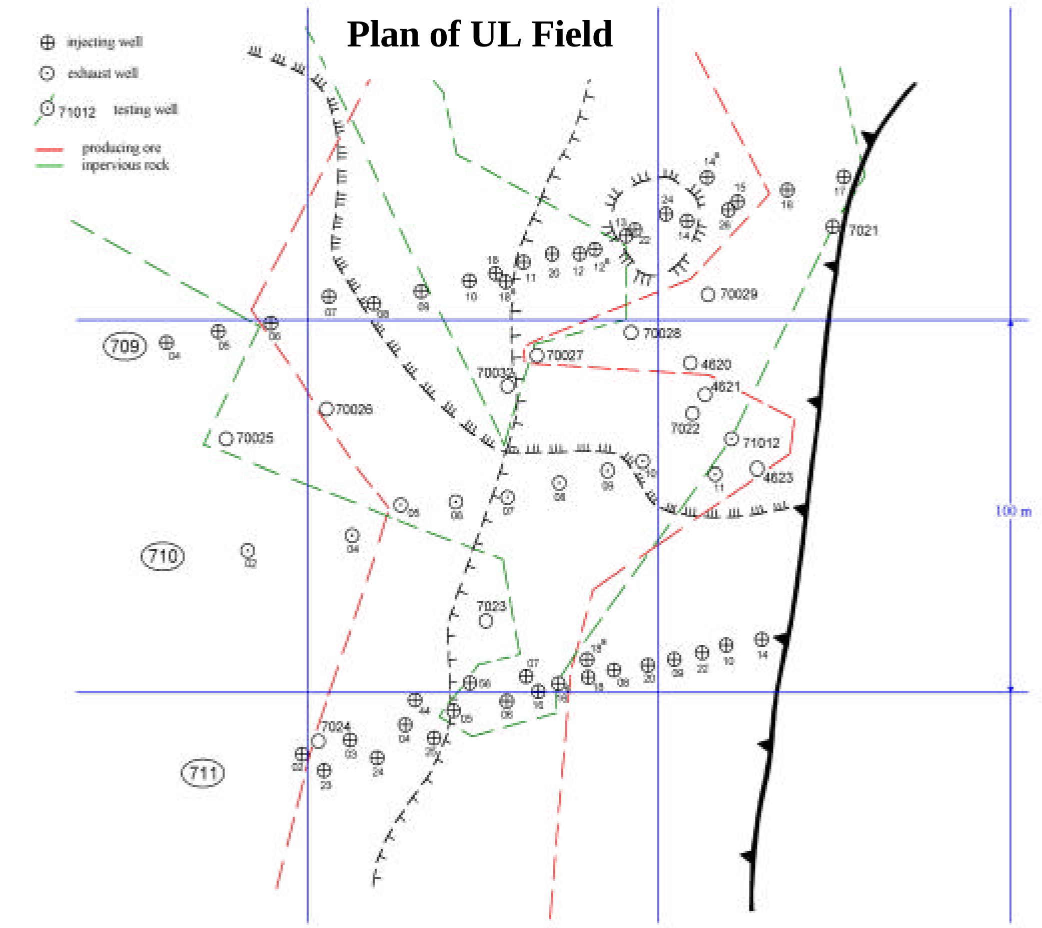

FIGURE 1.

in the borehole. One time, in December 1989, salt-acid treatment of the filter zone was done. The hole diameter is about 250 mm. The borehole is cased by a polyethylene tube with outer and inner diameters 210 and 174 mm, respectively, and is equipped with an edge filter located between benchmarks 148.8 and 158 m. The water level is about at a depth of 130 m. A pump-out method with output 1 – 3 m^3/h is used. Figure 5 shows the whole history of this exhaust well, i.e., the temporal dynamics of the relative concentration C and pH of pumped-out solution and the temporal dynamics of the output D. Areas *1*, *2*, and *3* correspond to times of acoustic stimulation and are considered below. The measurement of acoustic parameters of the productive seam in the region of the test borehole have the following results: velocity of longitudinal waves $c_l \sim 1900 \pm 100$ m/s, velocity of transverse waves $c_t \sim 980 \pm 120$ m/s, and logarithmic decrement for longitudinal waves $d \sim (1.5 - 3)\times 10^{-3}$. In the filter zone of the borehole, the resonance frequency of the antenna $f_r \cong 13.8$ kHz and the focal distance for longitudinal waves at this frequency $F \cong 5.5$ m. Moreover, the antenna radiates efficiently at the resonance frequency f_r^b of the water layer, which is located between the antenna surface and the borehole wall.

Exhausted wells cut

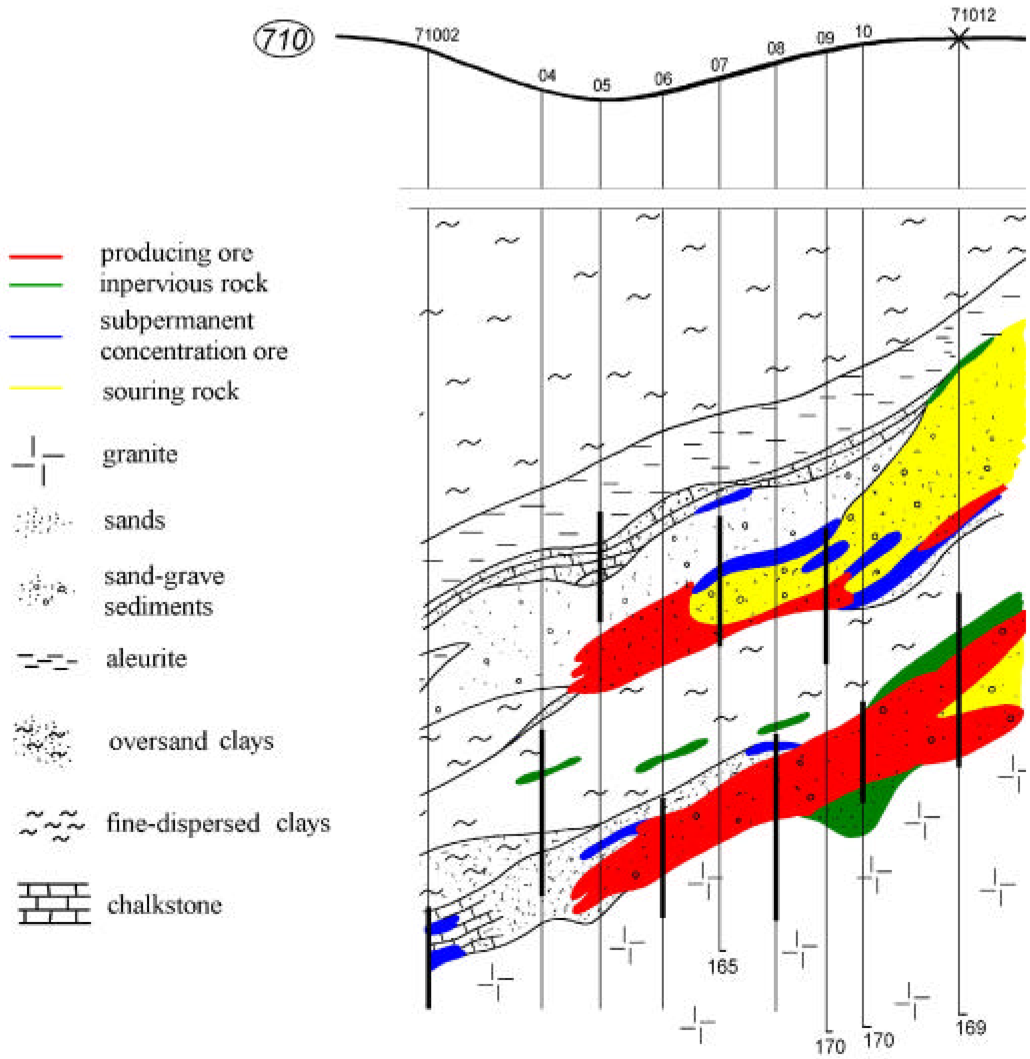

FIGURE 2.

Injecting wells cut

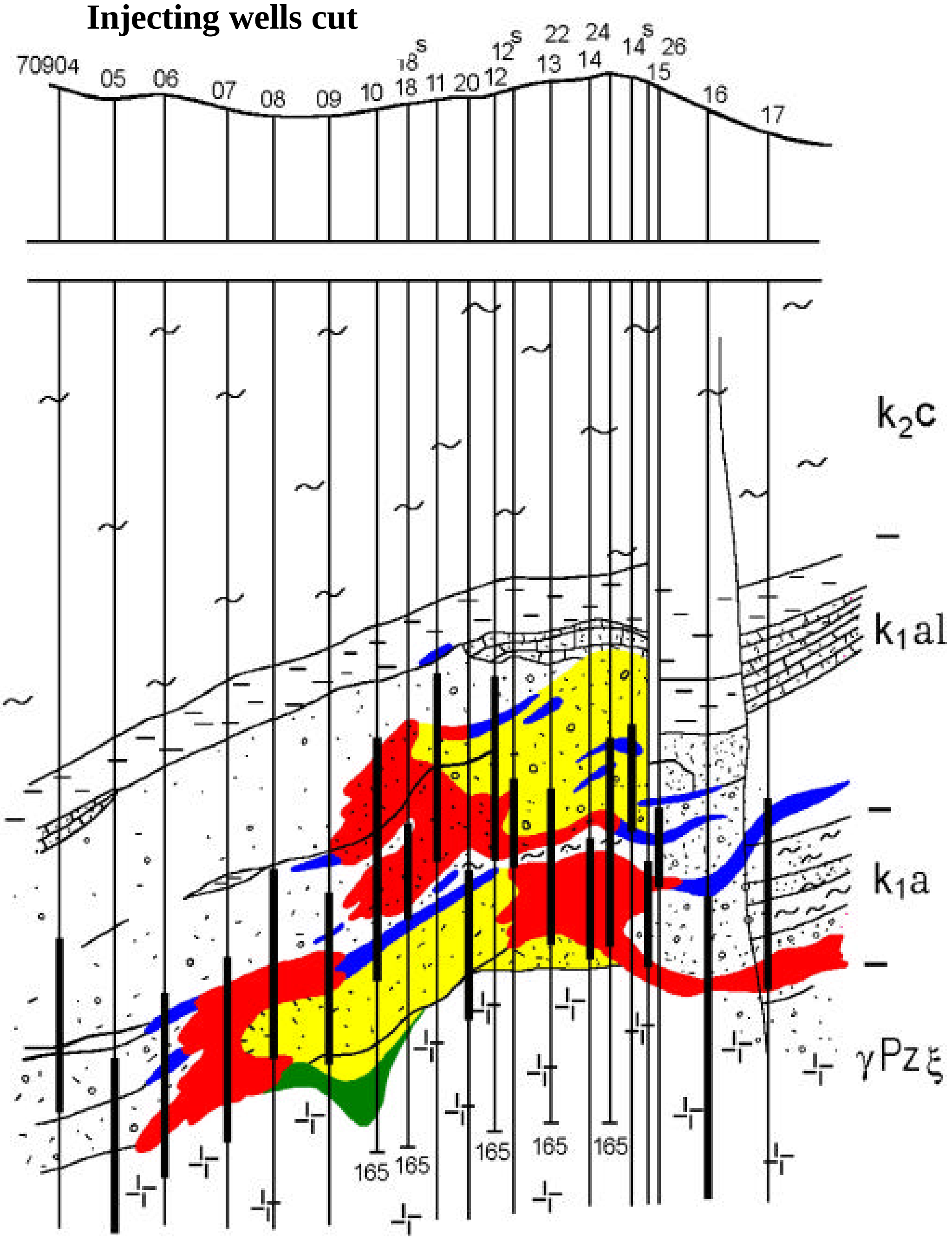

FIGURE 3.

FIGURE 4.

In the case considered, $f_r^b \cong 8.2$ kHz and the focal distance $F \cong 3.2$ m.

A detailed description of electroacoustic characteristics of this antenna and its operation modes in the described experiment is given in [18]. Figure 4 presents antenna modulus, which used in the experiment for cylindrical zone lens creation.

From October 29 to 30, 1989 (area *1* in Fig.5), we conducted tests of antenna modules and their combinations. Figure 6 presents area *2* in Fig.5. In this period of time, we did work on stimulation of UL using a focused field. Pumping-out was not conducted. The technology was as follows. The antenna was placed into the collector zone so as to make the focus (antenna center) at benchmark 150 m. After about each 20 minutes, the antenna was lowered 1 m to level 157 m at the center and then was uplifted in the same slow manner. In March 12, 1990, the stimulation was carried out at frequency 13.8 kHz for 16 hours.

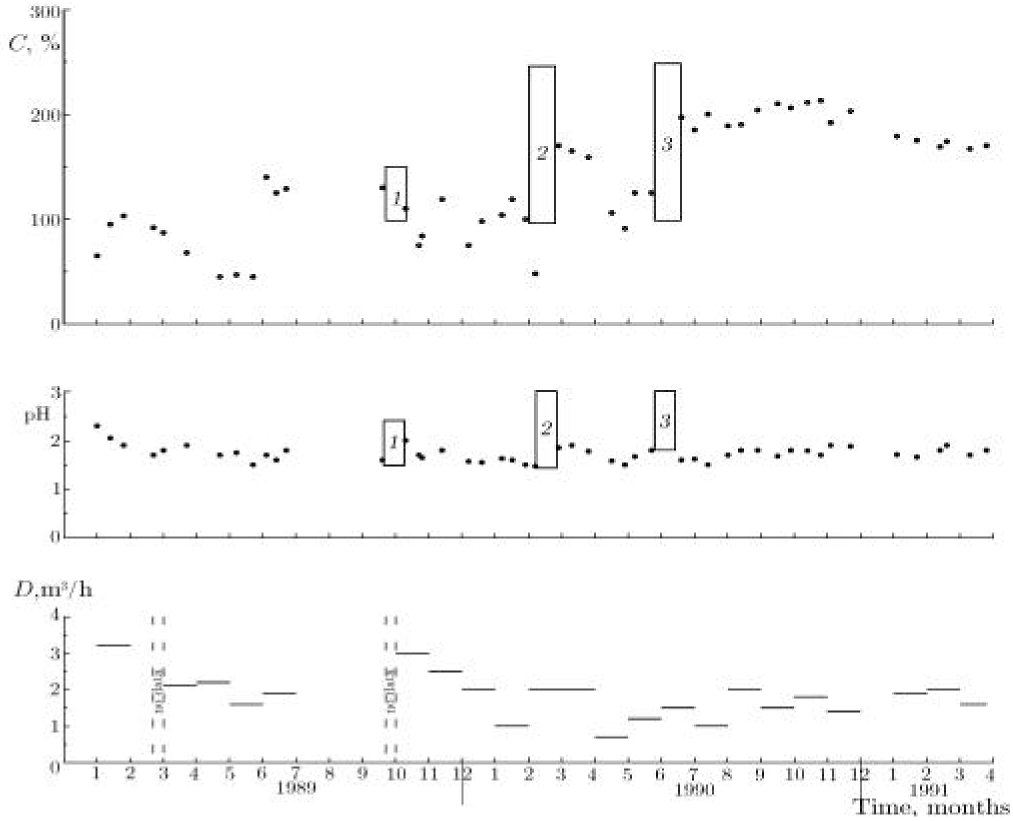

FIGURE 5.

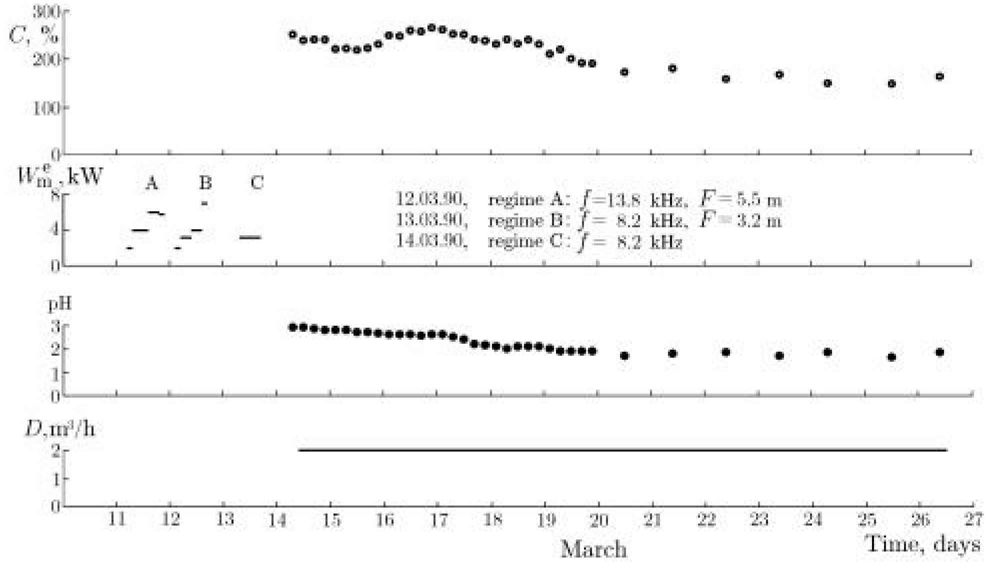

FIGURE 6.

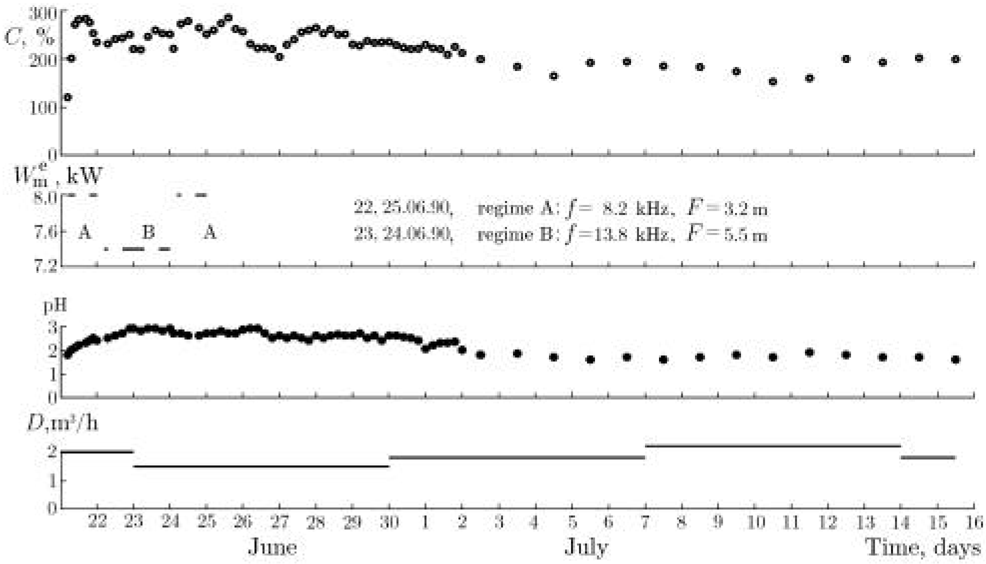

FIGURE 7.

The acoustic field was radiated in the form of a sequence of radio pulses with duration t_p ~ 6 ms. The pulsed electric power W_p^e was kept constant at a level of approximately 12 kW, and the mean electric power W_m^e was controlled by the on-off time ratio. According to estimates, the acoustic energy flux in the focus Π_F^p (F = 5.5 m) ~ 0.1 W/cm^2. In March 13, 1990, the stimulation was carried out using the same scheme but at frequency 8.2 kHz. In this case, F ~ 3.2 m and Π_F^p (F = 3.2 m) ~ 0.25 W/cm^2. March 14, 1990, we used not a focusing antenna but a combination of modules of length about 3 m, and the case of a cylindrically divergent acoustic field was realized. The stimulation was conducted at frequency 8.2 kHz in the continuous mode for 8 hours with Π_0^{cont} ~ 0.7 W/cm^2; the center of the antenna coincided with the filter center.

Figure 7 shows area *3* in Fig.5. In this period of time, the acoustic stimulation was conducted without interrupting the mining cycle, i.e., simultaneously with pumping out the productive solution. Initially, the focusing antenna was moved along the filter with velocity 1 ~ m/min using an electric winch. The antenna center corresponded to depth 150 m, then the antenna was lowered continuously for 7 min and was raised continuously for 7 min. The acoustic stimulation was carried out in the continuous mode in June 22 (the stimulation time T = 9 h) and June 25 (T = 10 h), 1990 at frequency *f* = 8.2 kHz for Π_0^{cont} ~ 0.7 W/cm^2, which corresponds to Π_F^{cont} (F=3.2 m) ~ 0.15 W/cm^2. Unfortunately, we couldn't increase Π_F^{cont} because of the rapid cavitation. In June 23 (T = 10 h) and June 24 (T = 14 h), 1990, the stimulation was conducted at the frequency *f* = 13.8 kHz for Π_0^{cont} ~ 0.7 W/cm^2, which corresponds to Π_F^{cont} (F = 5.5 m) ~ 0.06 W/cm^2.

Discussion

Analyzing Figs.1-3, the following main conclusions can be drawn. Under the action of an acoustic field, the concentration of the useful component in the pumped off solution increases sufficiently fast. Obviously, part of this increase in concentration is due to the immediate increase in the rate of the heterogeneous reaction affected by an acoustic field. The latter increase is related to the rise in the concentration gradient at the phase interface (see, e.g., [7]). This is indicated by the local concentration maxima in Fig.3, which follow directly after the field is switched on. Figures 2 and 3 also show the concentration maxima, which were recorded in the pump-out well several days after stimulation was terminated. Obviously, this results from the action of an acoustic field in the focal areas of the borehole antenna. The temporal position of the maxima, which occurred in March 17, 1990 (Fig.2), was strongly affected by the own hydrogeology of the stratum, since the pumping-out was activated in only March 15, 1990. The maximum recorded in June 28, 1990 (Fig.3) occurred under standard mining conditions, so that the time of its occurrence allows one, in principle, to determine such a characteristic as the filtration rate K_f for the given condition of pumping out. In the experiment, the results of which are presented in Fig.3, the reflexes from distances 5,5 and 3,2 m obviously overlapped. If this is the case, then K_f ~ 1,3 m/day, which conforms with the common view of the process [19]. Of course, one must take into account diffusion processes such as leveling of the concentration in a flow moving in a permeable medium, etc. Nevertheless, we are sure that, using focused fields, one can create not only a tool for UL stimulation but also a specific tool for study of this geotechnological process.

The strong residual effect of increased concentration, which we followed till April 1991 (the more recent data are absent), is less understandable. It should be mentioned that when the borehole was started, the deposit had already been used in the stationary mode, and the productive seam was strongly nonuniform in permeability and concentration. A weak solution of sulfuric acid is an active reagent in the leaching process. Interaction between the active reagent and the incorporating rocks must inevitably lead to the formation of a gas (for example, hydrogen) which, accumulating in capillaries and microcracks, makes the reaction surface three-phase. Further accumulation of gas makes the so-called gas colmatation, and part of the useful component on the capillary and microcrack walls turns out to be separated by gas from the liquid phase. Obviously, the elastic field accelerated abruptly gas diffusion from capillary-porous irregularities inside the seam within the range of elastic-field action. This removed the "gas barrier"' and, consequently, resulted in an irreversible increase in the area of the useful component active reagent interface.

CONCLUSIONS AND ACKNOWLEDGEMENTS

In conclusion, we emphasize again that the possibility of focusing divergent cylindrical waves discussed in this paper is of applied multi-purpose value. Indeed, use of such wave fronts seems to be promising in various borehole-acoustics problems such as studies of natural deposited rocks and stimulation of borehole mining of mineral resources by elastic fields. Moreover, experience shows that when focused fields are used for stimulation of geotechnological processes, geometric features of the acoustic field make it possible to develop different methods for express diagnostics of the geotechnological processes themselves.

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