UDC 628.396

I. O. Sadovenko, Dr. Sc. (Tech.), Prof.,
A. M. Zahrytsenko, Cand. Sc. (Tech.). Assoc. Prof.,
O. O. Podvihina, Cand. Sc. (Tech.),
N. I. Dereviahina, Cand. Sc. (Tech.)

State Higher Educational Institution "National Mining University", Dnipro, Ukraine, e-mail: alinanik@bigmir.net

WATER BALANCE CONTROL WITHIN ROCK MASS USING THE CAPACITY OF WATER-BEARING FORMATIONS

І. О. Садовенко, д-р техн. наук, проф.,
А. М. Загриценко, канд. техн. наук, доц.,
О. О. Подвігіна, канд. техн. наук,
Н. І. Деревягіна, канд. техн. наук

Державний вищий навчальний заклад „Національний гірничий університет", м. Дніпро, Україна, e-mail: alinanik@bigmir.net

РЕГУЛЮВАННЯ ВОДНОГО БАЛАНСУ В ПОРОДНОМУ МАСИВІ З ВИКОРИСТАННЯМ ЄМНІСНОГО Й ПОГЛИНАЛЬНОГО РЕСУРСУ ВОДОНОСНИХ ГОРИЗОНТІВ

Purpose. The articles aims to substantiate the nature of injecting liquid concentrate with the help of quantitative evaluation of both capacity and crossflow parameters of water-bearing formation involving geomechanical changes occurring in a rock mass.

Methodology. Numerical modeling of hydrodynamical and hydrochemical processes with repressive component under boundary conditions involving the model identification on the physical and dynamical analogy as well as solving filtration and crossflow problems; carrying out analytical study concerning conditions of vertical hydraulic fracturing of reservoir bed.

Findings. Both filtration and capacity parameters of water-bearing formation as well as crossflow parameters of low permeable separating formations have been substantiated. Changes in hydrodynamic and hydrochemical nature of underground water of reservoir bed and productive water-bearing formations under the conditions of injecting liquid concentrate and further relaxation of hydrodynamic repression in time and space have been evaluated. Geomechanical processes within the nearfield area have been taken into consideration by means of simulation selection of penetration parameters according to losses and injection pressure involving pulsation character of hydraulic fracturing of reservoir bed fissures.

Originality. For the first time ever mathematical model for liquid concentrate injection into water-bearing filtration with contiguous water extraction and pulsatory hydraulic fracturing character of the concentrate suction has been developed.

Practical value. Recommendations concerning a technically feasible and environmentally friendly operation mode of reservoir bed of liquid concentrate have been developed and implemented. Capacity reserves of reservoir bed have been evaluated according to a predictive category.

***Keywords*:** *filtration and cross flow processes, capacitive parameters, hydraulic fracturing, repression, relaxation*

Introduction. Pollution of the surface hydrosphere in Ukraine experiences its intensification due to increased disposal of waste water being over 20 km^3 a year. Almost 6 km^3 of it is untreated water and poorly treated water despite the fact that surface sources provide 80 % of public water supply in the country.

The problem of water management is the most burning in mining regions where disposals of mineralized water from mines and open pits disrupt hydrogeological and hydrochemical balance of river basins. For example, in Dnipropetrovsk region almost 50 million cubic meters of mine water is pumped out annually. Solid content of 30 million cubic meters of it is 3–5 g/dm^3; solid content of 20 million cubic meters of it is 14–30 g/dm^3. Water in the Samara River is characterized by high level of chlorides (0.2–0.8 g/dm^3), sulphates (0.55–1.6 g/dm^3), and dry residues (1.5–4.2 g/dm^3). The amount of suspended substances, oil products, and iron is 1.5–4 times higher to compare with the boundary permitted concentration. Such rivers as the Kalmius, the Inhulets, and the Saksahan located within a zone of intensive technogenic mining effect are heavily polluted as well.

Currently a number of techniques for mine water demineralization are available. Hot-processing techniques (distillation, freezing), membrane techniques (electrodialysis, reverse osmosis, ion exchange), hydrotechnical techniques and others are among them. However, they are not popular in mining practice due to considerable capital intensity and power consumption, lack of power resources and their high cost. The process of mine water demineralization is followed by the formation of salt brines. The matter is that a problem of their processing

---

and utilization has not been solved yet; besides, they should involve comprehensive approach.

Analysis of the recent research. The world practices use actively the injection of polluted water into reservoir rocks of deep formation of the earth's crust, i.e. subsurface waste water disposal.

The subsurface disposal of waste water (SDWW) has been initiated at the beginning of the last century by oilfields in the Russian Federation and in the USA. Highly mineralized formation water, extracted together with oil, is injected into non-productive wells and flooded wells. The paper [1] concerns the implementation of industrial waste water by "Gazprom" Ltd.

Most of all, subsurface disposal of waste water is popular in the USA. In addition to several dozens of injector wells in oil industry, landfills for subsurface disposal of waste water of other industries have been arranged. The number of such polygons increased from 35 in 1935 to 705 in 1997. Generally, sedimentary rocks (i.e. sands, sandstones, limestones, and dolomites) are basic accumulators for polluted water disposal. According to their depth, disposal wells are: down to 305 m – 6 %; 305 down to 710 m – 19; 710 down to 1420 m – 26; 1420 down to 2130 m – 34; 2130 down to 4260 m – 14; more than 4260 m – 1 %.

Subsurface disposal of waste water is widely used in Germany, Great Britain, France, Canada, and Japan.

Germany numbers several dozens of landfills for the disposal of subsurface waste water resulting from the activities of enterprises of potassium industry, chemical industry, and oil and gas industry. In terms of four objects, M. Buser [2] proposed scientific and technical background as well as organizing arrangement for toxic waste utilization. Injection is performed into carbonaceous rocks and terrigenous rocks; the injection depth is down to 1100 m and more. The injection intensity is 120–4800 m^3/day per a well whose mouth pressure is 1.0–2.0 MPa.

Near Whitchurch (Great Britain) industrial waste water has been injected into Cretaceous age deposits for more than sixty years.

In France, the first disposal well was drilled out at *Grandpuy* plant in 1970. Daily, 1100 m^3 of water with mouth pressure of 1.0 is injected into Jurassic limes within 1950–1980 m interval. Studies by P. Berest et al. [3] concern waste disposal in abandoned salt mines.

Japan performs a disposal of various types of industrial as well as domestic waste water. Thus, for many years acidic drain water has been injected into 150 wells drilled out from mine workings located in andesite formation with sandstones as a basement. The injection intensity is 13.000 m^3/day.

Ukraine has both positive and negative experience of liquid waste disposal. Since 1974 Pervomaisk chemical plant in Kharkiv region has performed a disposal of chloroorganic waste into Triassic sandstones deposited at the depth of 1650 to 1780 m and containing formation water with 140 g/dm^3 mineralization. Overburden of the lost circulation formation consists of clay- and sand-bearing beds of Jurassic, Cretaceous, and Palaeogenic Periods; Permian clays underlie it. Annually, 1.2 to 1.4 million cubic meters of waste water is injected within the landfill.

Since 1978 waste water into Lower Triassic formation has been injected periodically within Shebelynsk gas deposit. The injection depth is 880 to 1000 m.

Industrial waste intake into pure water-bearing formations, which took place at Horlivka chemical plant, and injection of waste water from Rubizhne chemical integrated works (Luhansk region) into sandstones of Middle Carbonic Period in Krasnopillia Dome, which resulted in the pollution of water-bearing formations used for water supply, are among the negative examples of liquid industrial waste disposal. Due to available hydrodynamically open system of faults, industrial wastes have been forced up by means of the action of confined groundwater.

Hence, subsurface disposal of polluted water is the complicated problem involving geological and hydrogeological, technological, economic, and environmental components [4].

Studies by V. M. Goldberg, M. P. Skvortsov, L. G. Lukianchikova, V. M. Shestakov, I. S. Pashkovskyi, S. P. Pozdniakov, B. P. Akulinichev, O. M. Sevastianov, Yu. M. Kondachkov, V. M. Kiriashkin and others have contributed significantly to the analysis of hydrodynamic processes within water waste landfills.

Unsolved aspects of the problem. Available geological and hydrogeological information concerning the territory of Ukraine makes it possible to evaluate, at least roughly, the prospects of industrial waste water injection in any region and district. Characteristics of intake bed, its capacitive and filtration features should become the basic criterion for geological and hydrogeological estimation of SWWD capabilities. Both national and world practices show that regional closeness helps prevent such negative after-effects of water injection as crossflow (leakage) of waste water into underlying and overlying formations containing pure water, balneologic water or commercial water.

Within the southern part of Ukrainian fundamental crystalline formation, where there is a pure water deficit, a sharp demand for liquid concentrate disposal after reverse osmosis has arisen since the concentrate is still discharging into hydrographic network. To preserve environmentally acceptable water balance of the region, it is required to substantiate the possibility for waste water disposal using a technique of numerical mathematical modeling of filtration and migration processes in the context of certain indefiniteness of regional hydrogeological conditions.

Objectives of the article. To substantiate the operation mode for liquid concentrate injection into water-bearing reservoir bed it is required to solve the following problems:

- determination of capacitive and crossflow parameters of water-bearing formation taking into consideration geomechanical changes in a rock mass;
- evaluation of reservoir bed isolatedness in the context of possible crossflow of liquid concentrates into contiguous water-bearing formations;
- evaluation of waste water circulation within the reservoir bed to substantiate controlled hydrochemical changes in subsurface water.

Presentation of the main research. Practices and experience of solving the problems connected with prognosis of hydrodynamical and hydrochemical changes in the process of subsurface disposal of industrial wastes show that the mathematical modeling method is the most adaptable and accurate one in terms of certain indefiniteness and multi-factor nature of both natural and simulated processes. The numerical mathematical model makes it possible to determine a dependence of level dynamics and losses of subsurface flows in the course of time and in terms of the area in an explicit form; to take into consideration a process of crossflow through separating layers with low permeability in the context of operation of injectors and water-supply wells; relation between subsurface water and surface water; infiltration recharge; temporal changes in boundary conditions and parameters; anisotropy of filtration features etc.

Modeling of liquid concentrate injection relies upon the basic differential filtration equation. The equation is solved with the help of numerical iteration methods on the basis of frames, i.e. a system of finite difference equations

$$T_x \frac{\partial^2 H}{\partial x^2} + T_y \frac{\partial^2 H}{\partial y^2} + W + Q_p + Q_n = \mu \frac{\partial H}{\partial t}, \qquad (1)$$

where H is the required pressure function, *m*; Tx and Ty are water conductivity of water-bearing formation towards x and y, m^2/day; W is a value of unit filtration, m/day; Q_p is a unit loss indicating relation with surface water flow, m^2/day; Q_n is a unit loss characterizing water-bearing relation through separating layers with low permeability, m^2/day; μ is elastic water, t is current time, days.

Formally, differential crossflow equation is similar to filtration equation being as follows

$$\frac{\partial^2 C}{\partial x^2} D_x + \frac{\partial^2 C}{\partial y^2} D_y = n\frac{\partial C}{dt} + \nu \frac{\partial C}{\partial x}, \qquad (2)$$

where C is the required concentration value, mg/dm^3; D_x and D_y stand for a diffusion coefficient on linear coordinates x and y correspondingly, m^2/day; ν is actual velocity of the substance motion, m/day; n is porosity; t is time, days.

Non-uniformity of the bedded formation is taken into account by means of a water conductivity parameter being reflected in terms of the model in the process of filtration area discretization.

The study object is represented by three-layer water-bearing formation. Calculated layer one is water-bearing formation of quaternary deposits; layer two is water-bearing system of Sarmatic Neogene limestones; layer three is Palaeogenic water-bearing formation within sandstone deposits. Water-bearing formations have hydraulic connection through separating layers with low permeability.

In terms of the plan, filtration field is represented by a grid of 69 × 76 components with irregular pitch decreasing from filtration area boundaries towards test group of wells (200 to 50 m) and occupying area of almost 114 km^2.

Palaeogenic water-bearing formation (calculation layer three) is considered as a reservoir bed. It is deposited in sandstones with 25 m thickness at the depth of 235 m. Over 100 m sandstone-clay formation is its overburden. Due to the limited amount of actual data concerning its mode of occurrence, the plan takes hydrodynamic boundaries of the 3rd type reflecting relations between losses and pressures. Losses with zero values are assumed according to water threads.

Solution of inversion problems is represented in the form of consequential multivariant calculation series in stationary formulation and transient one where effect on a level behavior of subsurface water of rock filtration coefficient variations, water yield, infiltration recharge, a parameter of contiguous water-bearing formations, imperfectness of streams etc. are evaluated. According to the results of factor and range analysis, input data bodies have been substantiated. That made it possible to balance the model (Table 1) and obtain the level state close to the actual one. Results of experimental and filtrational activities and long-term behavioral observations are those control data applied while solving the problem of both model and object identification.

Previous experimental and filtrational activities involved the construction of an injector 17194(2П) and observation wells (4П, 5Н, 6Н); geophysical analysis of lithological rock types; determination of water-bearing layers and those having low permeability; test unwatering of the injector and observation wells; test injection and experimental injection into 17194(2П) well.

Filtrational and capacitive parameters of Sarmatic and Palaeogenic water-bearing complex as well as analogous parameters of separating layers were corrected while using a model of test unwatering dynamics. According to the data, parameters of water-bearing formations and separating formations with low permeability have the following values:

1. The filtration coefficient of separating layer between calculation layers one and two is 2×10^{-3} m/day; and it is 1×10^{-6} m/day between calculation levels two and three.
2. Water-yield coefficient for Sarmatic deposits is as follows: 0.1 (gravitational), 10^{-4} (elasticity); in the context of Palaeogenic deposits is 0.02 and 10^{-5} correspondingly.

In terms of the mentioned parameters the hydrodynamic model is balanced within hydrodynamic boundaries for the period preceding the activities connected with water waste injection at the landfill (Table 1).

It should be noted that both under natural conditions and under operation conditions of water intake, within the test area, a level of subsurface water of Palaeogenic deposits (level three) is higher than the level of Sarmatic deposits (level 2) in terms of absolute elevation. In other words, ascending crossflow of subsurface water (7.1 m^3/day) through separating layer with low permeability occurs (Table 1).

While substantiating industrial water injection possibility, a problem of intake capacity of disposal wells has been solved. Injection rate absorption depends on a water-bearing bed as well as features of nearfield penetration formation. To determine the parameters, the following research-filtration actions (RFA) were previously taken: injection of the concentrate into Palaeogenic water-bearing formation (calculated layer 3 within the model). Rate of the absorption well 2-П varied as follows: 5 to 612 m^3/day when pressure was 0.3 to 17.37 atm.

Table 1

A balance of subsurface water of the model

Water input, m^3/day		Consumption components of the balance, m^3/day	
Calculated layer 2			
Infiltration recharge	195.2	Injection rate	3745
Influx within outer contour	1910	Discharge into a river	2126.5
Crossflow over a roof	3767.1	Evaporation	26
Crossflow over a subface	7.1		
Capacitive component	0.14	Capacitive component	0
Total:	**5879.5**	**Total:**	**58897.5**
Imbalance, %	**0.15**		
Calculated layer 3			
Influx within outer contour	9.8	Discharge within outer contour	2.9
		Crossflow over a roof	7.1
Capacitive component	0.06	Capacitive component	0
Total:	**9.9**	**Total:**	**10.0**
Imbalance, %	**0.8**		

Changes in a level mode were registered in observation well 6-Н located at a distance of 125 m from the injection one. According to the RFA interpretation data (Fig. 1), specific capacity of the well is almost 40 m^3/day.

To reconstruct a level of subsurface water dynamics in the context of RFA model, the process is divided into several periods; each of them involves injection-relaxation mode (Fig. 2).

Period 5 registers excessive temperature of the level change ($\Delta H = 88$ m) which can be explained by hydrofracturing. Its mechanism will be considered below. To understand filtration and capacitive parameters of Palaeogenic water-bearing formation as well as their changes, the model reconstructs injection-relaxation process with daily rate variations (Fig. 3).

The graph in Fig. 3 demonstrates that model level and actual level are congruent; however, imbalance is up to 1.1 m. The latter can be explained by inertial character of the rock mass and instability of the process. In this context, satisfactory similarity of the processes has been determined with the following parameters of the Palaeogenic water-bearing rocks:

1. Filtration coefficient is 0.1 m/day; it is 3 m/day within the nearfield area (probably, it is a result of hydrofracturing).

2. Coefficient of water-saturation lack is: elastic – $9.8 \cdot 10^{-5}$, gravitational – 0.2.

Reservoir bed parameters obtained using the model while solving inverse problems as for injecting and unwatering differ insignificantly; the difference depends on the achieved hydrofracturing effect. However, the latter ones are the most substantiated in terms of multivariant identification solutions; moreover, they have been assumed while forecasting a process of concentrated solutions burying.

Natural mineralization of subsurface water of the Palaeogenic water-bearing formation within the studied area is 33 to 40 g/dm^3 (34 g/dm^3 is assumed for the

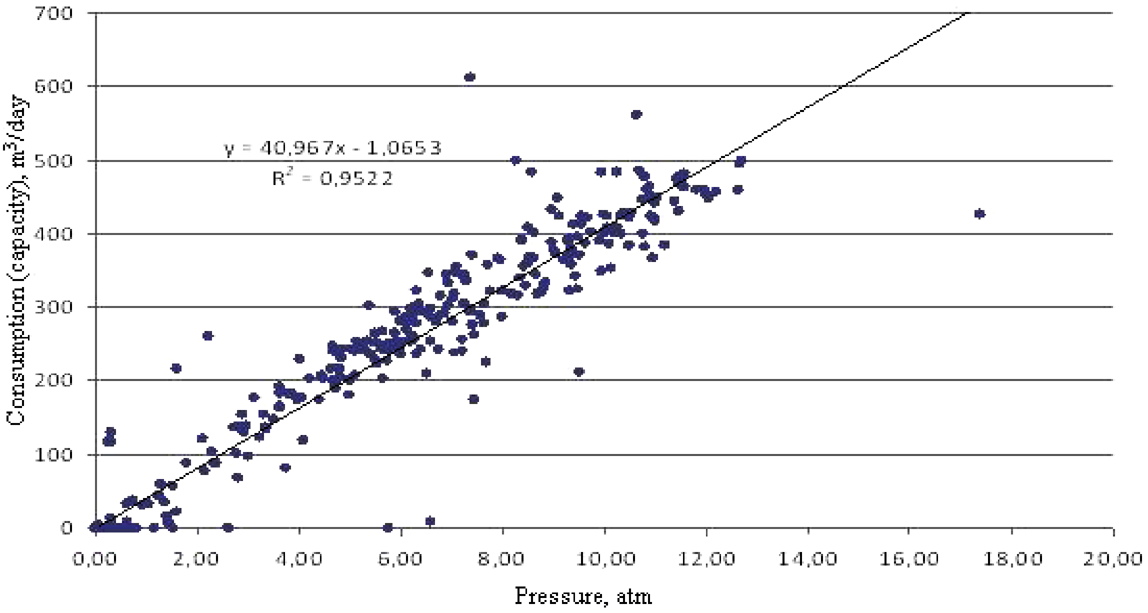

Fig. 1. Consumption-pressure dependence within the injection well 2-П

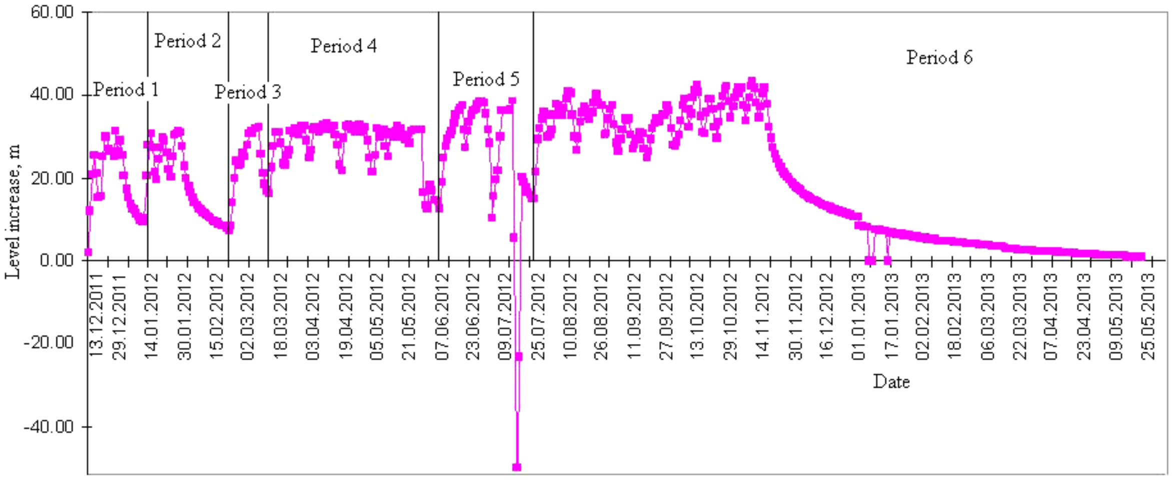

Fig. 2. Subsurface water level dynamics within the observation well 6-H while injecting concentrate

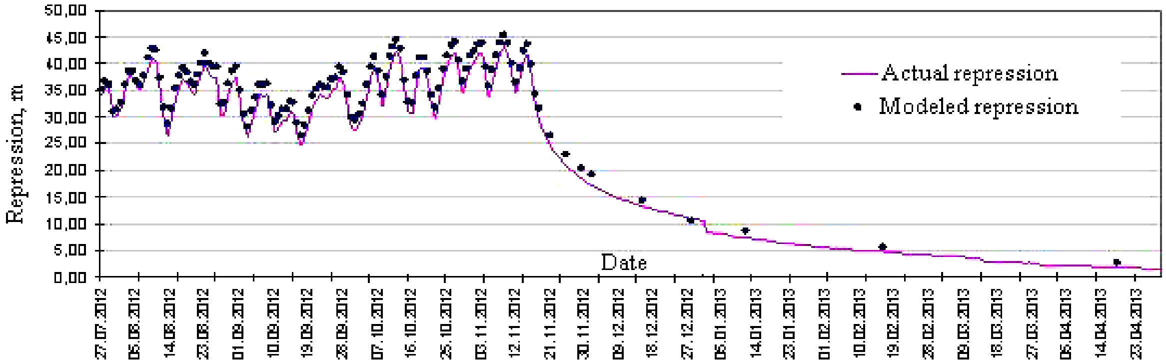

Fig. 3. Temporal repression variations within the observational well 6-H (period 6)

model). Mineralization of the injected solutions varied within 13.7–18.5 g/dm^3 (17 g/dm^3 is assumed for the model). The results of sampling from observational well 6-H for chemical analysis did not record any natural salt dilution while injecting (Fig. 4). Moreover, mineralization changes within Middle- and Upper Sarmatic formations are also within seasonal values meaning no effect of water injection.

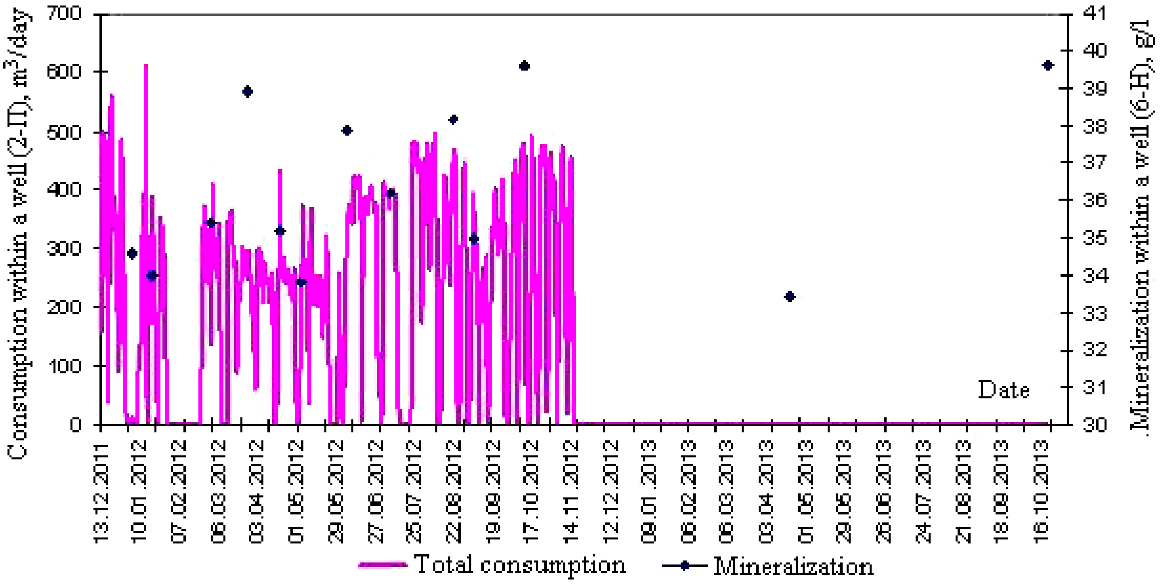

Fig. 4. Changes in subsurface water mineralization in the process of concentrate injection

However, such a tendency while solving reverse problem (Fig. 5) is possible if only porosity of Palaeogenic deposits is up to 20 %.

Substantiation of reservoir bed hydrofracturing parameters. Simulated hydrofracturing of rocks is divided into stages depending upon a level of available fracturing. In the context of monolith rock, hydrofracturing results from certain boundary pressure of liquid with further sharp absorption increase with lower pressure.

In reference to protogene hydrofracturing, expansion of fractures happens first. The process corresponds to a law of subsurface hydrostatics when actual stresses experience their increase within interfractural blocks. Then, hydrofracturing occurs whose stage is similar to secondary hydrofracturing of monolith rock with pressure being lower than that with protogene hydrofracturing.

Criteria of fracturing in the process of hydrofracturing are focused on combination of energy theory of Griffiths and regulations on fracture deformation in case of balance of forces either opening a fracture of preserving it from expansion.

The statement by S. O. Khristianovych is compatible with experimental data concerning rock hydrofracturing in the form of a fracture

$$1-\frac{g}{P}=\sqrt{1-a^2}, \qquad (3)$$

where g and P are rock pressure and pressure inside the fracture respectively; a is a coefficient being equal to linear dimension of the fracture expansion (R)-pressure application dimension (P) ratio if stress application is terminated within a point whose current linear dimension is (r) when $R/r = 1$.

Condition (3) for liquid with water viscosity means that within the considered cases, hydrofracturing originates if $P \to g$ being visualized with the help of the ratio

$$k\gamma\Pi_H > \gamma_B H_B, \qquad (4)$$

where H is the depth of rock bedding; H_B is water pressure; γ_Π, γ_B are density of rocks and water; k is coefficient of concentration of stresses (it is ≈ 1 in the neighborhood of absorption well).

Let us revise ratio (4) taking into consideration (3) for vertical fissure of hydrofracturing

$$k\gamma_\Pi H\left(\frac{\nu}{1-\nu}\right)=\gamma_B h_B, \qquad (5)$$

where ν is Poisson's ratio. It is obvious that for the considered conditions $\nu \approx 0.25...0.3$, execution of ratio (5) is quite admissible.

Water crossflow through hydrofracturing area may experience sharp increase resulting in equally sharp pressure drop. That factors into violation of condition (3) and closing of fractures. Further the pressure increases which may result in the next hydrofracturing period, i. e. the process becomes of pulsating character. In the context of mining practice such events are observed when mining operations are performed in the neighbourhood of flooded areas [5]. While injecting into the reservoir bed it becomes the fixation of permeability increase which should be supported by technical parameters of pumping equipment.

It should be noted that when hydrofracturing effect is achieved, geomechanical changes in the nearfield area are taken into consideration by means of simulation selection of permeability parameters according to the consumption and injection pressure.

Prognosis of hydrochemical repression formation has been carried out for such conditions when total water collection from Sarmatic water-bearing complex is 6900 m^3/day and daily amount of concentrated solutions being injected into Palaeogenic water-bearing formation is 720 m^3.

Formation process of hydrodynamic repression within the injection well (2-П) and the observation one (6-Н) takes almost a year (Fig. 6), and for the period of 25 years it is 256 and 147 m respectively. For the residu-

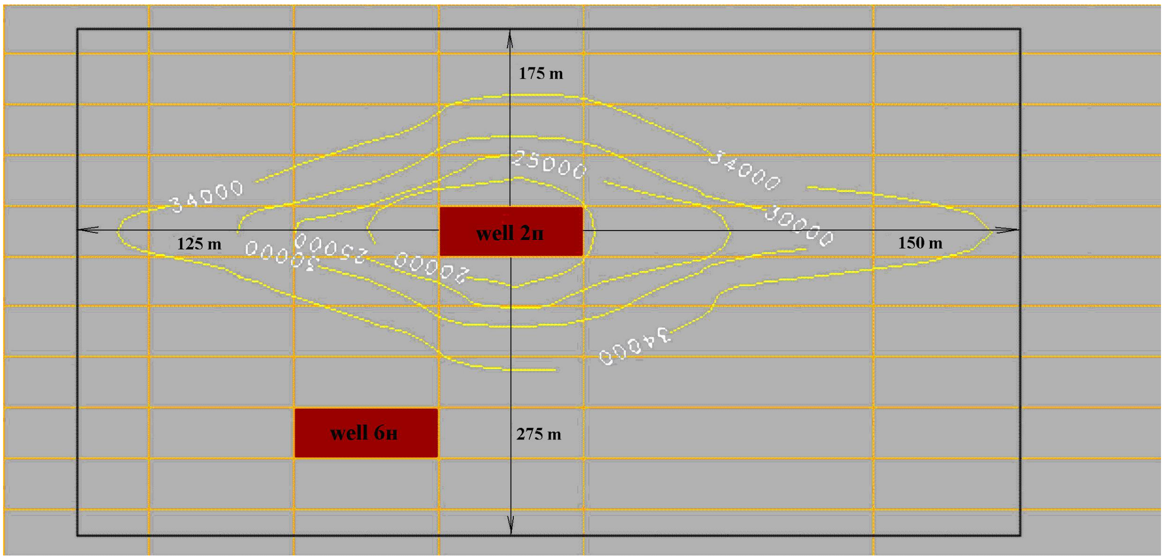

Fig. 5. A fragment of the model with mineralization isolines (mg/dm^3) while performing RFA with concentrated solutions injection

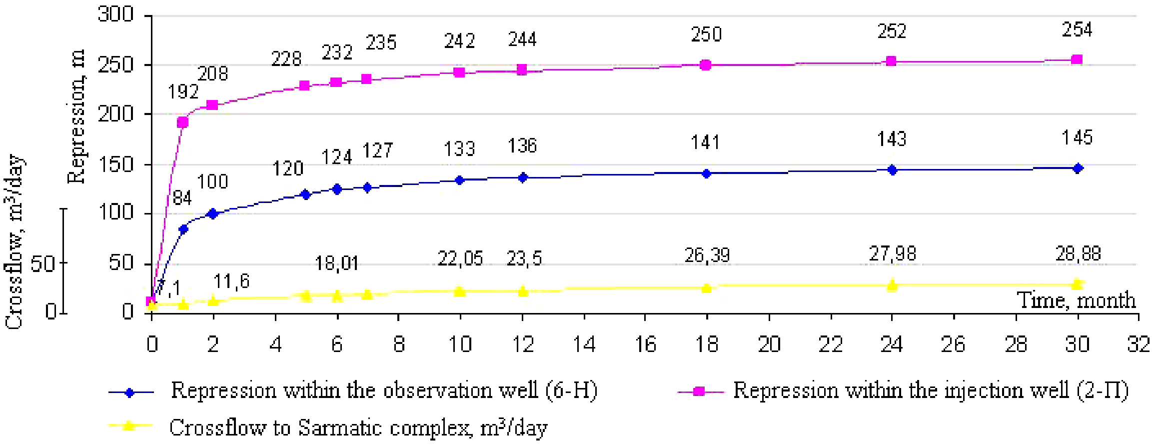

Fig. 6. Temporal formation of hydrodynamic repression

al period, maximum crossflow into Sarmatic water-bearing complex is 30.4 m^3/day (Table 2).

At the expense of dilution within the reservoir bed, decrease in natural mineralization occurs inside the territory of almost 1000 × 1000 m.

Temporally, hydrodynamical relaxation of the formed repression being 256 m (≈ 25 atm) proceeds under conditions of the elastic filtration mode taking 1.0–1.5 years only. After the relaxation year, final repression within the well is almost 11 m; after 2 years it is 3 m; and it is about zero after 3 years.

Dispersion of a zone with mineralization being close to a concentrate takes much more time. After a relaxation year hydrochemical situation remains almost unchangeable owing to the lack of convection component.

Increased crossflow into Sarmatic water-bearing complex (7.1 up to 30.4 m^3/day) cannot change mineralization of subsurface water of productive water-bearing complex drastically. Greater crossflow into Sarmatic water-bearing complex with lower salt content results in minor (up to 10 %) decrease in its mineralization.

Conclusions and recommendations for further research. At a radial distance of 50 m, effect of vertical hydrofracturing achieved within reservoir bed while liquid concentrate injecting increases filtration parameters of sandstones by three times; in terms of elastic capacity it is massively more. That is confirmed by the results of many numerical solutions of reverse problems in a mode of dewatering and injection. If a well capacity is 40 m^3/day × atm and waste water burying amount is 720 m^3/day then operational mode of the landfill is environmentally friendly since greater crossflow with lower salt content into upper water-bearing complex results in its decreased (down to 10 %) mineralization.

Generally, regarding the considered method, burying process of mineralized residues widens ways of filtration transit to a discharge zone. The fact should be con-

Table 2

Balance of subsurface water model for the forecast period up to 2037

Water input, m^3/day		Consumption components of the balance, m^3/day	
Calculated layer 2			
Infiltration recharge at the expense of precipitates	195.2	Water well rate	–6900
Influx within outer contour	4820.6	Discharge into a river	–1388.1
Crossflow over a roof	3238.9	Evaporation	–26
Crossflow over a subface	30.4		
Capacitive component	42.6	Capacitive component	0
Total:	**8327.7**	**Total:**	**–8314.1**
Imbalance, %	**+0.08**		
Calculated layer 3			
Injection rate	720.0	Discharge within outer contour	–689.6
		Crossflow over a roof	–30.4
Capacitive component	0.06	Capacitive component	0
Total	**720.0**	**Total**	**–720.0**
Imbalance, %	**0.0**		

sidered as conditions to intensify natural recovery which is impossible in the context of direct discharge into hydrographic network (or in the context of brine dilution) in accordance with palliative schemes.

Specific attention should be paid to monitoring of waste water burying since the neutralization method is to be applied exceptionally when it is impossible to use traditional methods of depollution and utilization involving a number of specific requirements and conditions.

References.

1. Ilchenko, V. P. ed., 2000. *Hydrogeoecological control on the landfills of industrial sewage pumping* (methodical guidance). Moscow: LLC "IRTS GAZPROM". [online] Available at: <http://www.docload.ru/Basesdoc/8/8059/index> [Accessed 13 May 2017].

2. Buser, M., 2016. *Endlagerung radio- und chemotoxischer Abfälle im Tiefuntergrund: Wissenschaftlich-technische, planerisch- organisatorische und strukturelle Schwachstellen – eine Beurteilung vier ausgewählter Fallbeispiele*. INA GmbH Zürich. [online] Available at: <https:/www.greenpeace.de/sites/www.greenpeace.de/files/publications/gp_studie_endlager_20_06_16_2_0.pdf> [Accessed 27 May 2017].

3. Berest, P., Brouard, B. and Feuga, B., 2004. Abandon des mines de sel: faut-il ennoyer? *Revue Française de Géotechnique*, 106–107: 53–72. [online] Available at: <http://www.brouard-consulting.com/sites/default/files/rfg-mines_1.pdf> [Accessed 13 May 2017].

4. Garaishin, A. S. and Kantiukov, R. R., 2017. Selecting Formation-Accumulator for Industrial Waste Disposal of Arbuzovsky Underground Gas Storage Facality. *Georesursy*, [e-journal] 19(1), pp. 82–86. http://doi.org/10.18599/grs.19.1.13.

5. Sadovenko, I. A., Demchenko, Yu. I. and Ulitskii, O. A., 2003. Evaluation of Geomechanical Stability of Inter-Shaft Pillars. *Collection of Scientific Labors of the NMU*, 1(17), pp. 40–43.

Мета. Обґрунтування режиму закачування рідкого концентрату на основі кількісної оцінки ємнісних і міграційних параметрів водоносного горизонту з урахуванням геомеханічних змін у гірському масиві.

Методика. Чисельне моделювання гідродинамічних і гідрогеохімічних процесів з репресивною складовою у граничних умовах, що включає ідентифікацію моделі за фізичною й динамічною аналогією та рішення прогнозних фільтраційних і міграційних задач. Аналітичне дослідження умов вертикального гідравлічного розриву пласта-колектора.

Результати. Обґрунтовані фільтраційні та ємнісні параметри водоносної товщі, а також параметри перетікання розділяючих слабопроникних товщ. Оцінені зміни гідродинамічного й гідрохімічного режиму підземних вод пласта-колектора та продуктивних водоносних горизонтів в умовах закачування рідкого концентрату та подальшої релаксації гідродинамічної репресії у часі й просторі. Ураховані геомеханічні процеси присвердловинної зони шляхом імітаційного підбору параметрів проникності відповідно до витрат і тиску закачування, що враховують пульсаційний характер гідророзриву тріщин пласта-колектора.

Наукова новизна. Уперше на основі синтезу аналітичних і чисельних рішень створена математична модель закачування рідкого концентрату до водоносного пласта з суміжним водовідбором і пульсуючим гідророзривним характером поглинання розчину.

Практична значимість. Розроблені й впроваджені рекомендації щодо технічно можливого та екологічно прийнятного режиму експлуатації пласта-колектора рідкого концентрату. Оцінено ємнісний ресурс пласта-колектора за прогнозною категорією.

Ключові слова: *фільтраційні й міграційні процеси, ємнісні параметри, гідророзрив, репресія, релаксація*

Цель. Обоснование режима закачки жидкого концентрата на основе количественной оценки емкостных и миграционных параметров водоносного горизонта с учетом геомеханических изменений в горном массиве.

Методика. Численное моделирование гидродинамических и гидрогеохимических процессов с репрессивной составляющей в граничных условиях, которое включает идентификацию модели по физической и динамической аналогии и решение прогнозных фильтрационных и миграционных задач. Аналитическое исследование условий вертикального гидравлического разрыва пласта-коллектора.

Результаты. Обоснованы фильтрационные и емкостные параметры водоносной толщи, а также параметры перетекания разделяющих слабопроницаемых слоев. Оценены изменения гидродинамического и гидрохимического режима подземных вод пласта-коллектора и продуктивных водоносных горизонтов в условиях закачки жидкого концентрата и последующей релаксации гидродинамической репрессии во времени и пространстве. Учтены геомеханические процессы прискважинной зоны путем имитационного подбора параметров проницаемости соответственно расходу и давлению закачки, отражающие пульсационный характер гидроразрыва трещин пласта-коллектора.

Научная новизна. Впервые на основе синтеза аналитических и численных решений создана математическая модель закачки жидкого концентрата в водоносный пласт со смежным водоотбором и пульсирующим гидроразрывным характером поглощения раствора.

Практическая значимость. Разработаны и внедрены рекомендации по технически возможному и экологически приемлемому режиму эксплуатации пласта-коллектора жидкого концентрата. Оценен емкостной ресурс пласта-коллектора по прогнозной категории.

Ключевые слова: *фильтрационные и миграционные процессы, емкостные параметры, гидроразрыв, репрессия, релаксация*

Рекомендовано до публікації докт. геол. наук В. Ф. Приходченком. Дата надходження рукопису 08.10.16.