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**DEVELOPMENT AND JUSTIFICATION OF A HYDRO-IMPULSE
METHOD FOR INCREASING ORE PERMEABILITY
IN CONDITIONS OF URANIUM BOREHOLE PRODUCTION**

Abstract. The technology of downhole uranium production used at mining enterprises in Kazakhstan is described, the factors affecting the decrease in the filtration characteristics of productive formations are studied in detail, and an effective method is described for increasing the downhole uranium production. The applied methods of intensification of downhole production at uranium mining enterprises are considered, the positive and negative aspects of the electropulse and chemical methods are discussed. Calculations of the working values of the hydro-wave method of destruction of clogging formations in the well and the parameters of the solution supply during repair and restoration work are presented. Based on the calculation of the operating parameters, a diagram of the dependence of the operating cycle of the hydropercussion machine on the flow rate of the water supplied to the machine is constructed. The developed 3D model of the hydropercussion apparatus for increasing the permeability of the productive horizon is presented. The advantages of the use of the hydrodynamic method for restoring the permeability of the productive horizon in the conditions of downhole uranium production in difficult mining and geological conditions are disclosed. The optimal parameters for intensification of downhole uranium production in difficult mining and geological conditions are recommended, and a method for using a hydropercussion apparatus in combination with traditional methods of well regeneration is developed.

Key words: Borewell, filter, clogging, hydraulic impulse, hydraulic machine, shock body.

Introduction. The technology of downhole uranium mining provides for the dissolution of a useful component at the location of the ore body, followed by the removal of the formed compounds by a moving stream of solvent from the injection well to the extraction well [1,2]. The practice of operating systems of geotechnical wells during the operation of uranium deposits by the method of underground drillhole leaching of uranium (ISL) shows that over time there is a decrease in their productivity. One of the main reasons for the decrease in the throughput of technological wells is an increase in hydraulic resistance and a decrease in the filtration characteristics of the reservoir as a result of the formation of clogging, due to the precipitation of substances dissolved in technological solutions, or mechanical movement of particles of the ore-bearing horizon, as well as gas release. The experience of operating such wells at the enterprises of the National Atomic Company (NAC) Kazatomprom JSC shows that the main reason for the decrease in their productivity and resource is the clogging processes of the rocks in the near-filter zone (NFZ) of the wells and the filters themselves.

Mechanical clogging is due to the overlap of the water intake openings of the filters with sand, clay, gravel and the clogging of the pore channels of the formation with mechanical suspensions. Sand and clay deposited in the well partially or completely overlap the filter. Also, clogging of the filter and the near-filter zone of the formation with drilling fluids containing clay particles can be attributed to mechanical

clogging. In this case, the swelling of clay material in the aquatic environment and a change in the structure of the pore space of the formation [3].

Chemical, ion exchange and gas types of clogging are caused by a change in the chemical composition of formation waters as a result of the influence of chemical materials used in ISL. The presence of dissolved calcium, magnesium and iron cation exchangers in water and a violation of carbon dioxide equilibrium leads to the formation of hardly soluble precipitates. Intensive precipitation of carbonate sediments occurs in the filter zone, and with distance from them, the intensity of precipitation decreases [4]. When leaching solutions interact with ore-bearing rocks in the liquid phase, there is an accumulation (in addition to ore) of a number of elements that make up the main rock-forming minerals. The amount and kinetics of the transition of these elements into productive solutions depends on the type of leaching agent, its concentration, redox potential, temperature, solubility of rock-forming minerals, and the size of the active surface of mineral particles, which largely determines the intensity of mass transfer in the solution-rock system.

In most cases, sediments, clogging filters and near-filter zones of wells are multicomponent and can simultaneously contain salts of iron, manganese and their hydroxides, calcium and magnesium carbonates, silicic acid and sulfides, as well as sand and clay. They are deposited on the surface of the filters and in the pores of the adjacent aquifers by gravity or adsorbed by surface tension forces. Over time, sludge is dehydrated and compacted. Deposits have a loose-porous and conglomerate structure and at different stages of formation and are characterized by different strength and activity to enter into a reaction. The formation of conglomerate-like sediments is associated with the processes of chemical and mechanical cementation adjacent to the filter of aquifers or gravel sprinkling with chemical deposits.

The main methods for restoring or increasing the permeability of bottomhole zone rocks during recovery and restoration work (RRW) are physical, chemical and combined. When choosing the RRW technology, one should proceed from the possibility of each method of declogging of filters and near-filter areas of wells. Also, when choosing a workover method, it is necessary to take into account hydrogeological conditions, drilling technology, well structure, filter and other characteristic factors of the field.

Review of literary sources. To restore the flow rate of wells by destroying and dispersing clogging deposits, which prevent the filtration of solutions in the reservoir in difficult mining and geological conditions, electrohydrodynamic methods of well regeneration are widely used. Table 1 shows the main methods used for the regeneration of wells in the conditions of ILS of uranium.

Table 1 – Applied RRW methods at uranium mining enterprises

The nature of the impact	Implementation method	Main purpose
Hydrodynamic	Compressor pumping	Removal of mud, mechanical suspended particles and impurities from the bottomhole formation zone (BHZ)
	Electroplasma	Removal of fine dust particles and clay materials from the BHZ
Chemical	Sulfuric acid	Dissolution of ferrous and aluminum chemical deposits
	Clay-acid	Dissolution of carbonate and silicon chemical and mechanical deposits
Combined	Reagent treatments with mechanical action	Removal of sand plugs from the columns and filter section of the well, dissolution of chemical deposits, intensification by swabbing, clarification of solutions by compressor pumping.

Analysis of the effectiveness of the impact of the electrohydroimpact (EH) method on the bridging deposits from the literature 5, 6, based on the creation of elastic resonant vibrations by electric discharges affecting the reservoir. Multiple sequential impulse vibrations in a wide range of frequencies are designed to destroy and disperse bridging formations and deep penetration and create new fractures in terigenic and carbonate reservoirs of different porosity and permeability. Also, during EH - treatment of a well, a low-frequency and ultra-low-frequency effect on the formation and its excitation at dominant frequencies at a considerable distance from the well occurs, which increases the permeability of solutions in the rock. In an electric explosion, a breakdown occurs between the electrode gap, in which the solution is located, with the formation of a rupture channel, the pressure in the channel increases, which is accompanied by its expansion. After the discharge stage, the channel turns into a gas bubble, which initially expands and then contracts under the pressure of hydrostatic pressure, creating alternating fluid movements. The main advantage of this method is that wells with filters made of almost any material, including asbestos-cement,

nylon or vinyl plastic pipes, can be treated with EH-treatment. Processing filters made of various materials requires changing the parameters of the power and pressure of the shock wave, its duration and the number of pulses per 1 m of its length, which determine the efficiency of the electric shock treatment of the filter. The pressure of the shock wave is mainly determined by the discharge voltage of the coaxial cable and the discharge gap in the downhole discharge device, adjustable up to 80 MPa, with a frequency of 1-10 Hz. The duration of the shock wave depends mainly on the capacity of the capacitor bank. However, the increased requirements for safe work practices, due to high voltage, provide for special training and additional equipment and devices, registration of work permits for maintenance personnel, which reduces the productivity of work and reduces the productivity of the installation.

In articles 7, 8, reagent methods for restoring the productivity of wells are presented, related to chemical methods of regeneration. Reagent methods of stimulating the formation are based on the reaction of aqueous solutions of acids with clogging formations, dissolution and removal of the reaction products outside the well, usually by airlift pumping. The choice of the type and method of reagent regeneration depends on many factors, which are determined by the composition and condition of the clogging sediment, the design of the filter and its condition, the structure of the treated surface. Regardless of the method of supply, hydrochloric acid HCl is widely used for well regeneration, effectively dissolving ferrous (Fe_2O_3 , $\text{Fe}(\text{OH})_3$, FeS) and carbonate (CaCO_3 , MgCO_3) bridging formations. The optimal working concentration of the hydrochloric acid solution is selected taking into account the dissolving ability and the rate of dissolution of the rock and the neutralization of the acid in the composition, corrosiveness and the magnitude of the formation pressure. In the practice of chemical treatment of wells, the method of reagent baths and the method of cyclic pressing into the formation are usually used. The reagent bath method involves pouring an acid solution at the wellhead, which, under the influence of diffusion processes, penetrates the filter circuit. Application of this method does not require additional equipment and sealing of the well head. The method of cyclic pushing of an aqueous acid solution into the formation is more effective than the method of reagent baths, however, it requires the installation of additional equipment, lowering of pipes and sealing of the well head. The practice of using chemical reagents in the regeneration of wells showed low efficiency of methods with especially difficult formation conditions (increased carbonate content of $\text{CO}_2 > 2\%$), sandiness of the well. There is no possibility to regulate the uniformity of filter cleaning both along the length and along the depth of the near-filter zone, since in the process of pressing with working solutions the reagent moves along the most permeable sections of the near-filter zone. In sealed, impermeable cemented formations, reagent methods require additional intensification of the process by hydrodynamic methods, since this allows to induce deep processes of acid-rock interaction.

Calculation and justification of operating parameters. The experience of the regeneration of geotechnical wells in carbonate blocks shows that the main reason for the low efficiency of many development methods is that each of them is aimed at solving a single problem: clay mud formation, filter and wellbore zone cleaning. It is necessary for the development to be comprehensive and include operations to restore the permeability of the near-filter zone and clean the filter from various kinds of sediment formation. These requirements are met by the pulse-wave method of regeneration, based on the action on the formation by hydraulic impulses in a solution of chemical reagents.

The generation of hydraulic impulses in a hydroimpact machine involves the use of hydraulic shocks that occur when the valve closes the fluid flow, produced by a striker on the anvil of the machine associated with a destructive tool. In this case, the most optimal solution would be to place generators in the filter zone of the well, i.e. generators must be submerged in the well. When creating a hydraulic impulse, due to the small gaps between the body of the transmitter and the production string of the well, due to the high velocity of the ascending flow and the inertial properties of the liquid, a pressure drop is created and the bridging agents are removed along with the liquid, i.e. In addition to the transfer of force, the liquid medium additionally removes destroyed bridging agents from the impact zone, which allows processing a significant part of the volume of the filter zone.

Based on the above parametric data, the average values of the frequency and energy of impacts, as well as the developed power of the hydraulic impact machine, were determined. The frequency of blows was determined by the formula 1. The energy of the blow is calculated by the formula 2.

$$n = \frac{1}{T}, \quad (1)$$

where: T – time of cycle, s.

$$W = \frac{m_6 \cdot V_6}{2}, \quad (2)$$

where: m_6 – striker weight; V_6 – striker speed during different stages of the cycle, cm/s; the mass of the striker is determined from expression 3.

$$m_6 = \frac{G_6}{g}, \quad (3)$$

where: g – acceleration of gravity, 9,81 m/s²;

The theoretical power of the machine is calculated from expression 4.

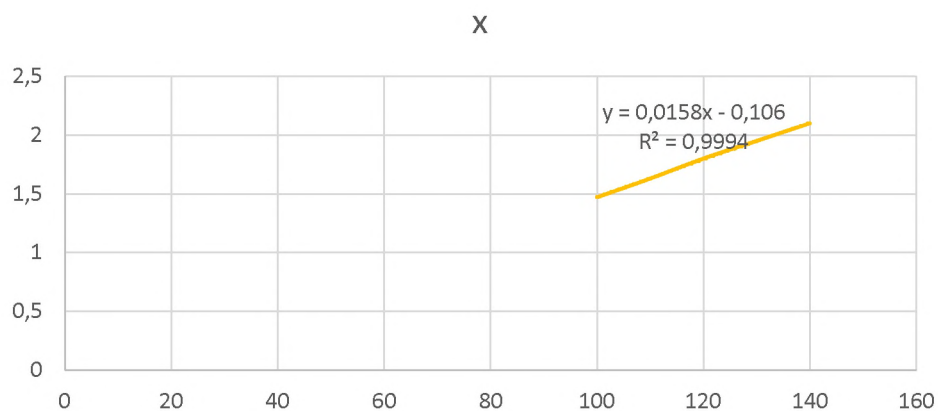
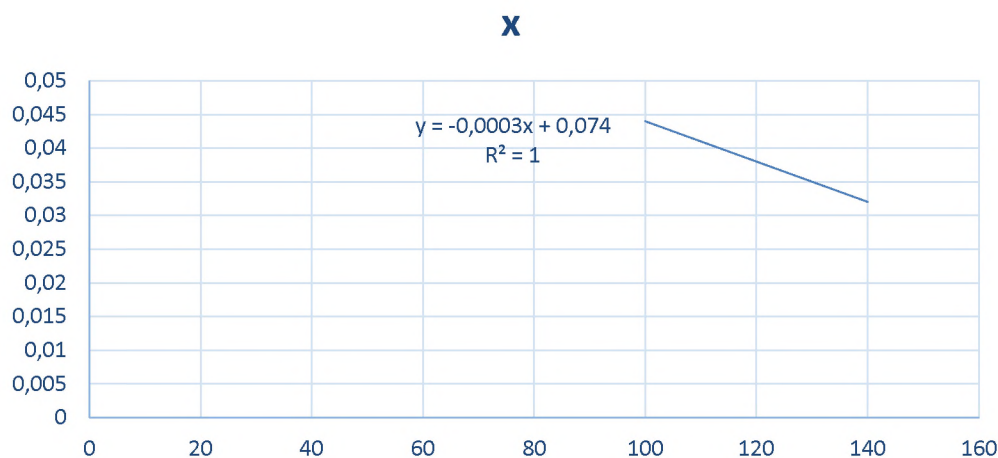
$$P = \frac{W \cdot n}{102}, kW. \quad (4)$$

The results are summarized in table 2.

Table 2 – Data of the dependence of the generator parameters on the flow rate of the supplied water

Water supply consumption $Q, l/min$	Total cycle time, T, s	Impact frequency $n, 1/s$	Striker pre-impact speed, $V_6, m/s$	Impact energy W, J	Theoretical machine power P, kW
100	0,044	22,7	1,47	6,5	0,14
120	0,038	26,3	1,80	9,7	0,25
140	0,032	31,2	2,10	13,2	0,40

Based on the calculated data obtained, graphs of the dependence of T , V_6 , and P on Q were built. The graph is shown in figure 1.



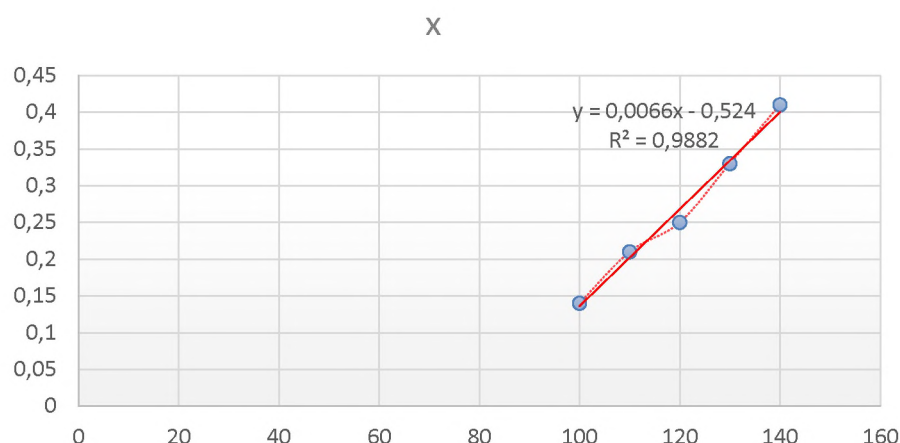


Figure 1 – Dependences of the operating cycle indicators of the hydraulic hammer machine on the flow rate of water supplied to the machine. 1 – $T = f(Q)$ graph; 2 – $V_0 = f(Q)$ graph; 3 – $P = f(Q)$ graph

The analysis of the given graphs showed that with an increase in water consumption, almost all cycle indicators increase, affecting the power of the machine, first of all, the pre-impact speed of the striker. A decrease in cycle time causes an increase in the pulse frequency, which also contributes to an increase in machine power.

According to the calculated values obtained and in accordance with the specific conditions of the well, a prototype of the hydroimpact apparatus was built, shown in figure 2.



Figure 2 – Diagram of a hydroimpact apparatus. a - 3D, b - in section. Where: 1 – body; 2 - connecting adapter; 3 - valve; 4 - sanding rings; 5 - spring; 6 - nozzle holes.

When flushing fluid is supplied through a continuous hose from HDPE to the bottomhole through adapter 2, flushing fluid creates pressure on the surface of valve 3, which, compressing the spring 5, moves until a jet of flushing fluid is fired through the side radial nozzle holes. The valve backstroke is provided when the mud pump pulsates, and the oscillating back and forth movement of the valve is equal to the pulsation per minute of a standard exploration mud pump. The failure-free operation of the device is ensured by the minimum number of moving parts relative to each other, the presence of sanding rings on the valve's working surface and, accordingly, by the simplicity of the design.

Conclusion. When the front of the reflected wave approaches the surface of the half-space, a wave arises that travels to the obstacle. As a result of the action of this wave, the compression of the medium is replaced by tension, the sign of the stress changes, and as a result, the sign of deformation. Multicomponent media do not withstand tensile deformations exceeding a certain critical value, which is different in bridging agent with different chemical compositions. Therefore, discontinuity occurs, and the tensile stresses corresponding to the rupture are usually of the order of the atmosphere.

In one-dimensional motions with hydro-impulse waves, all parameters depend on one single spatial coordinate and on time. The main sought functions are, in the general case, the stress tensor components, the density or volumetric deformation of the medium, and the mass velocity of the shock fluid, and the determining parameters are the constants entering the model equations and the boundary and initial conditions of the problem. In a medium with bulk viscosity, the result of the impact action will directly depend on the properties of the medium, the maximum pressure achieved and, in addition, on the wavelength. In media with bulk viscosity, the energy losses of waves can be different depending on their duration, respectively, the shorter the wave is, the smaller the losses during its propagation. This is an important property of viscous media.

From the analysis of wave propagation, it follows that at all considered distances the wave remains linearly shock, the maximum values of stress, strain and particle velocity are achieved at the front. Behind the front, all these quantities decrease, the voltage is distributed according to a linear law, the other parameters according to nonlinear laws, more slowly than the voltage. The lag of the extreme values of the deformation and the pulse velocity relative to the stress will not take place, however, a lag and decrease of these values behind the wave front is possible. The wave parameters at the front (precursor) both with a further decrease and with an increase in the voltage behind the shock can be obtained analytically without solving the problem as a whole.

The use of a hydropercussion wave directly, which creates alternating pressures on the inner cavity of the filter and then near the filter zone from the downhole hydropercussion machine, is the most promising direction for increasing the efficiency of RRW in technological wells. The use of the hydraulic impulse method of influencing the sealed formation zone during RRW of geotechnical wells is promising and cost-effective by reducing the time spent on the technological process and increasing the turnaround cycle.

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УРАНДЫ ҰҢҒЫМАЛЫҚ ӨНДІРУ ЖАҒДАЙЫНДА КЕННІҢ ӨТКІЗГІШТІГІН АРТТЫРУДЫҢ ГИДРОИМПУЛЬСТІК ӘДІСІН ӘЗІРЛЕУ ЖӘНЕ НЕГІЗДЕУ

Аннотация. Ұңғыманың түп аймағының сүзгісінің ішкі қуысында ауыспалы қысым жасайтын гидро-соққылы машинаның әсер ету әдісінің сипаттамасы мен жұмыс принципі келтірілген, бұл сүзгілердің де, сүзгі аймағының да қолматациясын төмендетуге көмектеседі.

Қазақстанның өндіруші кәсіпорындарында қолданылатын уранды ұңғымалық өндіру технологиясы сипатталған, өнімді қабаттардың сүзгілік сипаттамаларын төмендетуге әсер ететін факторлар жан-жақты зерделенген, сондай-ақ ұңғымалық уранды өндіруді арттырудың тиімді әдісі сипатталған. Уран өндіруші кәсіпорындарда ұңғымалық өндіруді қарқындатудың қолданылатын әдістері қаралды, электр көзді және химиялық әдістің оң және теріс жақтары талқыланды. Ұңғымадағы қолматациялық түзілімдерді бұзудың гидро толқындық әдісінің жұмыс мәндерінің және жөндеу-қалпына келтіру жұмыстарын жүргізу кезінде ерітінділерді беру параметрлерінің есептері келтірілген. Жұмыс параметрлерін есептеу негізінде гидравликалық соққы машинасының жұмыс циклы көрсеткіштерінің машинаға берілетін су шығынына тәуелділігі диаграммасы жасалды. Өнімді горизонттың өткізгіштігін арттыру үшін гидросоққылы машинаның 3D моделі келтірілген. Күрделі тау-кен геологиялық жағдайларда уранды ұңғымалық өндіру жағдайларында өнімді горизонттың өткізгіштігін қалпына келтірудің гидросоққылы әдісін қолданудың артықшылықтары ашылды. Күрделі тау-кен геологиялық жағдайларда уранды ұңғымалық өндіруді қарқындатудың оңтайлы параметрлері ұсынылды және ұңғымаларды қалпына келтірудің дәстүрлі әдістерімен үйлесімде гидросоққылы машинаны қолдану әдістемесі әзірленді.

Сүзгінің өткізу қабілетін және технологиялық ұңғымалардың сүзгі жанындағы аймағын (ЖҰШ) қалпына келтірудің негізгі міндеттерінің бірі қабаттың динамикасын, сондай-ақ олардың үдеуін, жылдамдығын және ығысуын ескере отырып, тұйықталған ортаға әсер ететін оңтайлы жүктемелерді айқындау болып табылады. Барлық осы шамалар тек қана тосқауылға түсетін толқынның параметрлеріне ғана емес, сонымен қатар кедергінің инерциялық және жиілік қасиеттеріне де байланысты. Уран кенін өндіру және эксперименттік зерттеулер кезінде технологиялық ұңғымалардың сүзгіш аймағын декольматациялау үшін гидроимпульсті

әдісті пайдалану шарттарына қатысты теориялық ережелер жүргізілді және негізделді. Гидропульстердің ұңғымалық генераторы арқылы жүзеге асырылатын гидропульстік әсер ортаның қасиетіне байланысты ағын қысымының гидропульсі ұңғыманың осінен 0,3 метрге дейінгі қашықтыққа таралуы мүмкін. Гидроимпульстік ағындардың әсерінен қабаттың сүзгі аймағының қолматантының бұзылуы ауыспалы циклдік тербелістің салдарынан болатындығы көрсетілген. Гидродинамикалық модель су толқындарының әсерінен сүзгі қабатының өткізгіштігінің өзгеру процесін сипаттайды. Гидродинамикалық модельдің көмегімен есептерді шешкен кезде ұңғымада және резервуардың қолматантты аймағында гидроимпульсті толқындардың таралу сипатын графиктер түрінде зерттеу үшін теңдеулер алынды.

Бұл гидросокқылы машинаның талқандау қабілеті теориялық және компьютерлік модельдеумен расталды. Келесі нәтижелер алынды. Біріншіден, гидросокқылы машина декольматацияны жоғарылатудың басқа құралдарына қарағанда әлдеқайда тиімді. Екіншіден, сокқының әсері сокқы элементінің қысымы мен соғу жиілігіне байланысты. Үшіншіден, импульстік ағын неғұрлым үлкен болса, оның талқандау қабілеті соғұрлым жоғары болады. Төртіншіден, импульстік ағынды құралдың саптамасының диаметрін азайту арқылы көбейтуге болады. Бесіншіден, гидравликалық сокқы жоғары қаттылықтың қолматациясының жойылуын тездетуге көмектеседі, ал аз цементтелген жыныстардың бұзылуы импульстік ағынның жоғарылауымен едәуір күшейтілуі мүмкін. Өзірленген импульстік гидросокқылы машина терең және көлденең ұңғымалардағы бұрғылау жылдамдығының төмендігі, шламды алып тастау сияқты мәселелерді шешудің жаңа идеясын ұсынады деген қорытындыға келдік.

Түйін сөздер: ұңғыма, сүзгі, қолматация, гидроимпульс, гидро машина, сокқы денесі.

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РАЗРАБОТКА И ОБОСНОВАНИЕ ГИДРОИМПУЛЬСНОГО МЕТОДА ПОВЫШЕНИЯ ПРОНИЦАЕМОСТИ РУД В УСЛОВИЯХ СКВАЖИННОЙ ДОБЫЧИ УРАНА

Аннотация. Приведено описание и принцип действия метода воздействия гидроударной машины, создающей знакопеременные давления на внутренней полости фильтра призабойной зоны скважины, которая способствует снижению кольматации как самих фильтров, так и прифильтровой зоны (ПФЗ).

Описана технология скважинной добычи урана, применяемая на добычных предприятиях Казахстана, подробно изучены факторы, влияющие на снижение фильтрационных характеристик продуктивных пластов, а также описан эффективный метод, повышения скважинной добычи урана. Рассмотрены применяемые методы интенсификации скважинной добычи на уранодобывающих предприятиях, обсуждены положительные и отрицательные стороны электроплазменного и химического метода. Приведены расчеты рабочих значений гидроволнового метода разрушения кольматационных образований в скважине и параметров подачи растворов при проведении ремонтно-восстановительных работ. На основе расчета рабочих параметров построена диаграмма зависимости показателей рабочего цикла гидроударной машины от расхода подаваемой в машину воды. Приведена разработанная 3D модель гидроударного аппарата для повышения проницаемости продуктивного горизонта. Раскрыты преимущества применения гидроударного метода восстановления проницаемости продуктивного горизонта в условиях скважинной добычи урана в сложных горно-геологических условиях. Рекомендованы оптимальные параметры интенсификации скважинной добычи урана в сложных горно-геологических условиях и разработана методика применения гидроударного аппарата в сочетании с традиционными методами регенерации скважин.

Одной из основных задач восстановления пропускной способности фильтра и прифильтровой зоны технологических скважин (ПСВ) является определение оптимальных нагрузок, действующих на закольматированную среду, с учетом динамики пласта, а также их ускорений, скоростей и смещений. Все эти величины существенно зависят не только от параметров волны, падающей на кольматантную преграду, но и от инерционных и частотных свойств самой преграды. Была проведена и обоснованы теоретические положения применительно условиям использования гидроимпульсного метода для декольматации прифильтровой зоны технологических скважин при добыче урановых руд и экспериментальных исследований. Гидроимпульсное воздействие, осуществляемое через скважинный генератор гидроимпульсов, в зависимости от свойства среды, гидроимпульса давления потока может распространяться на расстояние до 0,3 метра от оси скважины. Показано, что разрушение кольматанта прифильтровой зоны пласта под действием гидроимпульсных струй происходит за счет знакопеременного циклического колебания. Составлена гидродинамическая модель опи-

сывающей процесс изменения проницаемости прифилтрового пласта под воздействием гидроударных волн. При решении задач с помощью гидродинамической модели, получены уравнения для исследования характера распространения гидроимпульсных волн в скважине и кольматантной зоне пласта в виде графиков.

Разрушающая способность этого гидроударника была подтверждена теоретически и компьютерной моделированием. Были получены следующие результаты. Во-первых, этот гидроударник намного эффективнее, чем другие инструменты для повышения декольматации. Во-вторых, ударный эффект зависит от давления и частоты удара ударного элемента. В-третьих, чем больше импульсная струя, тем выше ее разрушающая способность. В-четвертых, импульсная струя может быть увеличена за счет уменьшения диаметра сопла инструмента. В-пятых, гидравлический удар может помочь ускорить разрушение кольматации высокой твердости, а разрушение менее цементированных пород может быть значительно усилено за счет увеличения импульсной струи. Сделан вывод о том, что разработанный импульсный гидроударник дает новую идею для решения таких проблем в глубоких и горизонтальных скважинах, как низкая скорость бурения, очевидный эффект прижима стружки и трудное удаление шлама.

Ключевые слова: Скважина, фильтр, кольматация, гидроимпульс, гидро машина, ударное тело.

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