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CONCEPT OF NUMERICAL EXPERIMENT OF ISOLATION OF ABSORPTIVE HORIZONS BY THERMOPLASTIC MATERIALS

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КОНЦЕПЦІЯ ЧИСЛЕНОГО ЕКСПЕРИМЕНТУ ІЗОЛЯЦІЇ ПОГЛИНАЮЧИХ ГОРИЗОНТІВ ТЕРМОПЛАСТИЧНИМИ МАТЕРІАЛАМИ

Purpose. Development the theoretical foundations of isolation of absorptive horizons using melts of fusible thermoplastic materials for the construction of algorithms and the creation of a complex of programs that allow calculating heat and mass transfer processes with the use of computers in a wide range of conditions.

Methodology. The problem is solved by a comprehensive study including analysis and synthesis of the literature and scientific and technological achievements in various fields of economic activity, mathematical, physical modeling, numerical methods of solution.

Findings. A general concept of computing experiment in theoretical modeling of processes of heat and mass transfer in elimination of absorption of washing liquid in the well is developed. The theoretical foundations of the isolation of absorptive horizons using melts with the construction of an algorithm for creating a complex process of calculating the heat and mass transfer program with the use of computers in a wide range of conditions.

Originality. The theoretical basis of the isolation of absorptive horizons using bulk melting of fusible thermoplastic materials was further developed. For the first time, an algorithm of creating complex programs that allow for calculation of heat and mass transfer processes in elimination of washing liquid absorption by the bulk melting of granular fusible thermoplastic material is offered.

Practical value. The practical significance lies in developing the method of isolating absorptive and unstable horizons for the implementation of which it is necessary to perform the following operations: delivery of granular thermoplastic material on the bottom of the well, local heating of the washing liquid, melting and squeezing thermoplastic material melt in the absorption channels.

Keywords: *drilling, well, absorptive horizon, washing liquid, absorption, isolation, plugging materials, downhole heat source, thermoplastic materials, melt, heat and mass transfer*

Problem statement. Ukraine has got significant mineral reserves. To engage these stocks in the operation, there must be a significant increase in exploration and production wells. Drilling of wells in areas where intensive mining operation is underway is inevitably fraught with complications the process of drilling.

Unsolved problem. Technical and economic parameters of drilling to a large extent are determined by the time and cost spent to eliminate complications. One of the most common complications is the absorption of washing liquid. According to statistics, their elimination consumes up to 20 % of time and money of the overall cost of well construction. Absorption leads to disruption of the process of drilling regime, provoking accidents and breakdowns.

Analysis of recent research. Bulatov A. I., Vozdvizhenski V. I., Volokitenkov A. A., Gaivoronsky A. A., Ivachev L. M., Kipko E. Ya., Krylov V. I., Lipatov N. K., Myslyuk M. A., Polozov Yu. A., Rafieko I. I., Spichak Yu. N., Titkov N. I., Tian P. M., Yakovlev A. M., Yasov V. G. and others devoted their research in the development of formulations of plugging materials and technologies to deal with absorption of washing liquid.

Analysis of the research shows that today there is a great diversity of methods and materials to eliminate the absorption of washing liquid. In most cases, the elimination of absorptions is provided by plugging the channels of washing liquid escape, or by hardening or non-hardening plugging mixtures by creating a waterproof screen in the rock around the well.

Currently, the majority of ways to eliminate the washing liquid absorption is based on the use of insufficiently effective cementing materials, which are water-based with the addition of mineral-cohesive or synthetic substances. The main disadvantage of these materials is that they have a high sensitivity to dilution by water: the solution is easily mixed with the washing liquid and the reservoir water, especially in the presence of cross-flows. There is a dilution, sedimentation of plugging mixtures leading to an increase in the setting time, spreading to considerable distances from the well, and as a result leads to significant cost overruns of plugging materials, to the need for frequent repetition of plugging operations, a significant overrun in time to eliminate the complications in the well.

Determination of unsolved aspects of the problem. To solve this problem, it is necessary to search for new technologies based on other physical processes, and other plugging materials that are not susceptible to dilution with water. These processes may include methods of making adhesive coating, based on the change in the aggregate state of plugging material, allowing to create succinct but quite durable and impermeable insulation shell around the well. Therefore, the actual problem is the development of non-conventional insulation technology for absorbing horizons based on filling the channels of absorption with melts of low-melting materials.

As an alternative to the currently applied technologies, at the National Mining University there has been developed a new alternative technology, in which the absorption channels are not filled with plugging material, but with melt of thermoplastic plugging material with a low melting point [1].

The thermoplastic material is chemically inert, it is not subject to the effect the aggressive water. It is easily drilled and does not stick to the technological tool. Its physical properties are independent of the storage time. Its cost is comparable to the cost of cement, and much less than the cost of synthetic resins. Due to the low melt viscosity of the thermoplastic material, it easily penetrates into rock with a slight opening of cracks. The strength of grouting stone obtained by cooling of the melt is comparable to the strength of the cement stone. Moreover, in the early stages of the hardening of thermoplastic material, strength is much higher than compressive uniaxial strength of the cement stone [2].

To implement the proposed technology, it is necessary to perform the following operations: deliver granular thermoplastic material to the bottom of the well, provide local heating of the washing liquid, melt thermoplastic material, squeeze thermoplastic material melt in the absorption channels.

One scheme of this method involves the use washing liquid as a heat carrier in a borehole in the zone of the absorbent horizon. Heating of the washing liquid in the well is carried out by downhole electric heater in such a way as is done in the electrothermal treatment of wells.

Statement of the aim of the research. In order to solve practical problems of calculating the required time of heating the washing liquid and the low-melting material, the temperature field, the radius around the well formed insulation shell, etc., it is necessary to study the processes of heat and mass transfer in absorbing horizon area.

The aim is to develop the theoretical foundations of the isolation of absorptive horizons using melts of fusible thermoplastic materials for the construction of algorithms and the creation of a complex of programs that allow for calculation of heat and mass transfer processes with the use of computers in a wide range of conditions.

Main material. Theoretical study of these processes is now possible to carry out through numerical simulation method using a computer. This approach assumes a significant role in view of the fact that their experimental study in the laboratory or in a downhole environment is very difficult and expensive, and becomes even impossible in some cases.

The general concept of a computational experiment. Computer experiment in its most advanced form consists of the following steps [3]:

- selecting a physical model of the investigated phenomena;
- selecting a mathematical model that is in more or less adequate to physical one;
- selecting and developing numerical method for displaying a continuous mathematical model in its final full-scale analogue;
- creating an appropriate computer program.

To the listed items can be added further comparison with the results of numerical simulation of physical modeling data (laboratory or well) and, therefore, if it is necessary to improve the mathematical model.

Physical and mathematical formulation of the problem. In general, for the implementation of the proposed technology, the following operations must be performed: local heating of the washing liquid in the well bottom zone, delivery, and squeeze of low-melting material, followed by the change in phase conditions in the pores and cracks of absorptive horizon.

Step one. In the step of washing liquid heating, the mathematical model looks as follows. Physical heating of the liquid in the well is made by heat conduction and free convection processes in the field of gravitational forces, and in the rock mass only by thermal conductivity [3–6]. Consequently, in the rock mass the temperature field is described by the heat equation [4]

$$\frac{\partial T}{\partial \tau} = a\Delta T, \quad (1)$$

and in liquid, by Navier-Stokes equations in the Boussinesq approximation, in alternating current-vortex function [3]

$$\frac{\partial \omega}{\partial t} + u\frac{\partial \omega}{\partial x} + \nu\frac{\partial \omega}{\partial y} = \\ = \nu\Delta\omega - g\beta_m\left(\frac{\partial T'}{\partial y}\sin\varphi - \frac{\partial T'}{\partial x}\cos\varphi\right); \quad (2)$$

$$\Delta\varphi = \omega, \quad (3)$$

and energy equations [5]

$$\rho C_p\left(\frac{\partial T'}{\partial t}+u\frac{\partial T'}{\partial x}+\nu\frac{\partial T'}{\partial y}\right)=\lambda'\Delta T, \qquad (4)$$

where Δ – is Laplassa operator.

Dissipative coefficients are α – thermal diffusivity, λ – coefficient of thermal conductivity, $C_п$ – specific heat at constant pressure, ρ – density of the material. The boundary conditions for this system include the homogeneous boundary conditions for the velocity field and the boundary conditions for the temperature. By y coordinate we have

$$\frac{\partial T'}{\partial y}_{|y=0,y_L}=0. \qquad (5)$$

From the symmetry conditions with respect to x on the axis of symmetry, it follows that

$$\frac{\partial T'}{\partial x}_{|x=R}=0. \qquad (6)$$

At the boundary of 'liquid – rock' boundary conditions of the 4th kind are set

$$T'_{|x=2R}=T_{x=0};$$
$$\lambda'\frac{\partial T'}{\partial x}_{|x=2R}=\lambda\frac{\partial T}{\partial x}_{|x=0}. \qquad (7)$$

The boundary conditions (5–7) are at the ∈ [0, *yL*], where *yL* defines the area of the heated liquid. According to the x-coordinate (for equations 1–4), the local coordinate systems are introduced. The following notations are accepted: $x = R$, where R – is radius of the well, for the rock mass $x \in [0, \infty]$.

Step two. Low-melting material is delivered into a heating zone in granules. Melting of fusible material is delivered in two stages. At the first stage the material is warmed. As soon as the surface temperature of the granules of fusible material reaches the temperature of phase transition the melting begins. In this formulation, the task corresponds to the Stefan problem [4–7]. From physical considerations it follows that this task can be considered as one-dimensional for each granule. The mathematical statement of the Stefan problem is formulated as follows [4, 5]. Temperature field of granules in warm mode is described by the heat equation,

$$\frac{\partial T}{\partial \tau}=a\frac{\partial^2 T}{\partial x^2}, \qquad (8)$$

with initial conditions

$$T_{|\tau=0}=T_0, \qquad (9)$$

and boundary conditions

$$\frac{\partial T}{\partial x}_{|x=0}=0; \qquad (10)$$

$$\lambda\frac{\partial T}{\partial x}_{|x=x\alpha}=\alpha\left(T_L(r)-T_{|x_L}\right), \qquad (11)$$

where α – is heat-exchange coefficient; T_L – is liquid temperature.

In addition to conditions (9–11) it is necessary to introduce the conditions at the boundary of the phase transition. On the surface of the phase transition $x=\xi(\tau)$ there remains a constant value of the phase transition temperature

$$T_{|x=\xi(\tau)}=T_\varphi, \qquad (12)$$

and the conditions of thermal balance are observed

$$\lambda_1\frac{\partial T_1}{\partial x}_{|x=\xi}-\lambda_2\frac{\partial T_2}{\partial x}_{|x=\xi}=L_\varphi\rho\frac{\partial \xi}{\partial \tau}, \qquad (13)$$

where *L*φ – is specific heat of fusion; ξ(τ) – is unknown law of displacement of the boundary; λ_1, λ_2 – are thermal conductivity factors of solid and liquid phases, accordingly.

Assume that the temperature of the material (granule) in a molten state takes a known value of borehole liquid temperature T_L. Then, at the introduction of conditions

$$T_{|x=x_L}\geq T_\varphi, \qquad (14)$$

the solution of the Stefan problem is reduced to solving warming problem for equation (8) with the conditions (9–11) [7]. Thus, from the expression (14) is determined the time τ = τφ corresponding to the beginning of melting granules. Thus, from the moment of time τ > τφ the temperature field of granules will be described by equation (8) with boundary conditions (10) and

$$T_{|x=\xi(\tau)}=T\varphi, \qquad (15)$$

where ξ(τ) – is defined from the equation

$$\frac{\partial \xi}{\partial \tau}=\frac{a/x_L}{K_0T_\varphi}(T_L-Q_L), \qquad (16)$$

with initial condition

$$\xi_{|\tau=\tau_\varphi}=x_L. \qquad (17)$$

In equation (16) the following notations were accepted

$$Q_L=\frac{\alpha x_L}{\lambda}(T_L-T_\varphi);$$
$$K_0=\frac{L_\varphi}{C_pT_\varphi}, \qquad (18)$$

where K_0 – is the Kossovich criterion.

Step three. The problem of changing the aggregate state of 'liquid – solid' corresponds to the Stefan problem by the mathematical formulation [5]. In this case, the temperature field of liquid phase is described by energy equation (4), where the components of velocity vector *u* and *υ* are assumed to be known. The liquid phase moves in a flat channel giving heat to the rock mass. As soon as the temperature reaches the melt phase transition temperature, a layer of fusible material of the solid phase is formed on the walls. This process continues until all of the melt turns into a solid state.

Conclusions and prospects for development. In this paper, the theoretical basis of the isolation absorptive horizons are developed using melts in order to build algorithms and create a set of programs that allow for calculation of heat and mass transfer processes with the use of computers in a wide range of conditions.

Transition from mathematical models (1–18) to a numerical algorithm, implemented by computer, is currently done using a grid method. In addition, for the construction of economical difference schemes it is advisable to use a splitting scheme. For the solution of the Stefan problems, algorithm for constructing a design scheme on the solutions of the Cauchy problem proves to be effective. It is advisable to create the programs aimed at solving the problems stated above in the form of a software package.

References/Список літератури

1. Brazhenenko, A. M., Kozhevnikov, A. A. and Sudakov, A. K., 2006. Technology isolation zones absorption of drilling wells using thermoplastic materials, *Nauka ta innovaciyi*, Vol. 2, No. 3, pp. 101–110.

Бражененко А. М. Технология изоляции зон поглощения буровых скважин с применением термопластичных материалов / А. М. Бражененко, А. А. Кожевников, А. К. Судаков // Наука та інновації. – 2006. – Т. 2. – № 3. – С. 101–110.

2. Brazhenenko, A. M., Goshovskiy, S. V. and Kozhevnikov, A. A., 2007. *Tamponazh gornyih porod pri burenii geologorazvedochnyih skvazhin legkoplavkimi materialami* [Plugging of rocks with the drilling of exploration wells fusible materials], UkrGGRI, Kiev, Ukraine.

Тампонаж горных пород при бурении геологоразведочных скважин легкоплавкими материалами / [А. М. Бражененко, С. В. Гошовский, А. А. Кожевников и др.]. – К.: УкрГГРИ, 2007. – 130 с.

3. Dreus, A. Yu., 2013. *Matematychni metody doslidzhennia teploobminu* [Mathematical methods for the study of the heat transfer], DNU, Donetsk, Ukraine.

Дреус А. Ю. Математичні методи дослідження теплообміну / Дреус А. Ю. – Донецьк: Вид-во ДНУ, 2013. – 130 с.

4. Bengt Sunden. Bengt Sunden, 2012. Introduction to heat transfer. WTI Press, Southampton, Boston.

5. Samarski, A. A., 2009. *Vychislitelnaia teploperedacha* [Computational heat transfer], Moscow, Russia, *Knizhni dom LIBROKOM*.

Самарский А. А. Вычислительная теплопередача / Самарский А. А., Вабищевич П. Н. – М.: Книжный дом „ЛИБРОКОМ“, 2009. – 480 с.

6. Akulich, P. V., 2010. *Raschety sushilnyh i teploobmennyh ustanovok* [Calculation of drying and heat-exchange plants], Minsk, Belarus, *Navuka*.

Акулич П. В. Расчеты сушильных и теплообменных установок / Акулич П. В. – Минск, Бєларус. Навука, 2010. – 434 с.

7. Schevchenko, A. I., 2012. *Zadacha Stefana pri nalichii konvektsii* [Stephen's problem at the presence of convection], Reports of the National Academy of Sciences of Ukraine, No. 1, pp. 25–29.

Шевченко А. И. Задача Стефана при наличии конвекции / А. И. Шевченко, А. С. Миненко // Доповіді Національної академії наук України. – 2012. – №1. – С. 25–29.

Мета. Розробка теоретичних основ ізоляції поглинаючих горизонтів із застосуванням розплавів легкоплавких термопластичних матеріалів для побудови алгоритмів і створення комплексу програм, що дозволяють вести розрахунок процесів тепломасопереносу із застосуванням ЕОМ у широкому діапазоні умов.

Методика. Поставлені задачі вирішувалися комплексним методом дослідження, що включає аналіз і узагальнення літературних джерел і науково-технічних досягнень в різних областях господарської діяльності, математичне, фізичне моделюваня, численні методи рішення.

Результати. Розроблена загальна концепція обчислювального експерименту для теоретичного моделювання процесів тепломасопереносу при ліквідації поглинання промивальної рідини у свердловині. Розроблені теоретичні основи ізоляції поглинаючих горизонтів із застосуванням розплавів з побудовою алгоритму для створення комплексу програм розрахунку процесу тепломасопереносу із застосуванням ЕОМ у широкому діапазоні умов.

Наукова новизна. Отримали подальший розвиток теоретичні основи ізоляції поглинаючих горизонтів із застосуванням об'ємного плавлення легкоплавких термопластичних матеріалів. Уперше запропоновано алгоритм створення комплексу програм, що дозволяють вести розрахунок процесів тепломасопереносу при ліквідації поглинання промивальної рідини методом об'ємного плавлення гранульованого легкоплавкого термопластичного матеріалу.

Практична значимість. Полягає в розробці технології ізоляції поглинаючих горизонтів, для реалізації якої необхідно виконати наступні технологічні операції: доставку гранульованого термопластичного матеріалу на забій свердловини, локальний нагрів промивальної рідини, плавлення й задавлювання розплаву термопластичного матеріалу в канали поглинання.

Ключові слова: *буріння свердловин, свердловина, поглинаючий горизонт, промивальна рідина, поглинання, ізоляція, тампонажні матеріали, забійне теплове джерело, термопластичні матеріали, розплав, тепломасоперенос*

Цель. Разработка теоретических основ изоляции поглощающих горизонтов с применением расплавов легкоплавких термопластичных материалов для построения алгоритмов и создания комплекса программ, позволяющих вести расчет процессов тепломассопереноса с применением ЭВМ в широком диапазоне условий.

Методика. Поставленные задачи решались комплексным методом исследования, включающим анализ и обобщение литературных источников и научно-технических достижений в различных областях хозяйственной деятельности, математическое, физическое моделирование, численные методы решения.

Результаты. Разработана общая концепция вычислительного эксперимента для теоретического моделирования процессов тепломассопереноса при ликвидации поглощения промывочной жидкости в скважине. Разработаны теоретические основы изоляции поглощающих горизонтов с применением расплавов с построением алгоритма для создания комплекса программ расчета процесса тепломассопереноса с применением ЭВМ в широком диапазоне условий.

Научная новизна. Получили дальнейшее развитие теоретические основы изоляции поглощающих горизонтов с применением объемного плавления легкоплавких термопластичных материалов. Впервые предложен алгоритм создания комплекса программ, позволяющих вести расчет процессов тепломассопереноса при ликвидации поглощения промывочной жидкости методом объемного плавления гранулированного легкоплавкого термопластичного материала.

Практическая значимость. Состоят в разработке технологии изоляции поглощающих и неустойчивых горизонтов, для реализации которой необходимо выполнить следующие технологические операции: доставку гранулированного термопластичного материала на забой скважины, локальный нагрев промывочной жидкости, плавление и задавливание расплава термопластичного материала в каналы поглощения.

Ключевые слова: *бурение скважин, скважина, поглощающий горизонт, промывочная жидкость, поглощение, изоляция, тампонажные материалы, забойный тепловой источник, термопластичные материалы, расплав, тепломассоперенос*

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APPLICATION OF PULSE-WAVE TECHNOLOGY FOR OIL WELL COMPLETION

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ЗАСТОСУВАННЯ ІМПУЛЬСНО-ХВИЛЬОВИХ ТЕХНОЛОГІЙ ДЛЯ ОСВОЄННЯ НАФТОВИХ СВЕРДЛОВИН

Purpose. Substantiation of the intensity values of elastic waves in the bottom-hole zone required to form a network of cracks in the formation as well as pilot verification of the results.

Methodology. Analytical and experimental research studies have been carried out on the clays sandstone with a tensile strength of 2.4 MPa, which has been treated by pressure pulses with duration of the leading front of up to 5 ms and amplitude of up to 6 MPa. The parameters of the research studies have been measured by standard equipment ATM-38.

Findings. The calculations confirm the possibility of creating variable pressure with amplitude of more than 1.2 MPa in the reservoir at a distance of 1 m from the downhole hydraulic generator. Industrial studies indicate the possibility of creating stresses in a near-wellbore zone which exceed the limit of the fatigue strength of the rock. This results in formation of additional cracks in the bottom-hole zone and, thus, more effective completion of the wells.

Originality. It is a new approach to the selection of the downhole generator parameters for creating a network of cracks in the formation on the basis of fatigue fracture rock.

Practical value. The results of the research can be used for testing the influence of cyclic stresses on the increasing quantity cracks in coal layers for degassing them and for creating new technologies of the oil and gas wells completion.

Keywords: *oil, elastic waves, frequency, wells completion*