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Determination of the thermal state of a block gravel filter during its transportation along the borehole

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Abstract

Purpose. Development of a methodology for determining the thermal state of block inverse gravel filters manufactured using low-temperature technology during their transportation in a well based on computer and mathematical modeling.

Methods. The study of hydrodynamic processes occurring during the transportation of the filter in the borehole, as well as the calculation of thermal fields in the filter body, was performed using the Ansys Fluent software package. To determine the effective thermophysical characteristics of the filter, the approaches of the heat transfer theory in porous media were applied. To investigate the thermal conditions of the filter at heat exchange with well fluid, the use of analytical solution of the heat conduction problem in a cylindrical shell, taking into account the properties of porous dispersed water-saturated medium, is proposed.

Findings. The methodology for calculating the thermal state of a gravel filter during its operation in a well has been developed. For estimation of the filter surface temperature, the expression obtained on the basis of the analytical solution of the heat conduction equation, taking into account the characteristics of the porous filter medium, is proposed. Hydrodynamic and thermal fields in the borehole and the filter body during the filter transportation process in the borehole have been obtained.

Originality. For the first time, the problem of heat exchange of a gravel inversion filter, manufactured by low-temperature technology in a well is considered. The influence of hydrothermal conditions in the well on the process of filter heating during its transportation in the well is shown. The hydrodynamic fields during the flow of the drilling mud around the inverse gravel filter are determined.

Practical implications. The proposed approaches and results of the study allow to determine and can be used in the development of technological regulations for the use of block gravel filters produced by low-temperature technology for the equipment of hydrogeological wells.

The methodology for modelling the process of two-phase inversion transition of aggregate state of the binding agent during transportation of inverted block-type gravel filter during well construction has been developed.

Keywords: *well, binding agent, gravel filter, temperature field*

1. Introduction

The quality of the well and its operational characteristics are determined by a set of technological works carried out at the final stage of its construction, which includes opening the aquifer, equipping it with a filter and development [1], [2].

The choice of filter type is determined primarily by the particle size distribution of the rocks containing water. Of particular difficulty are issues related to the disclosure of aquifers represented by medium-grained, fine-grained and silty sands [3]-[5], and the installation of gravel filters in the water intake part of the well.

Two main types of gravel filters are used in groundwater extraction: downhole gravel filters assembled on the ground surface and then installed in wells in a ready-to-use form, and gravel filters built in the well using gravel that is poured or pumped into the well by the annular space [6]-[8].

When drilling wells of small and medium depths (up to 100 m) gravel filters with loose backfill created by pouring gravel between pipes are successfully used. When drilling deeper wells with a small end diameter, as well as when opening pressurized aquifers that spill out to the ground surface, the creation of such gravel filters becomes difficult, and in some cases impossible [9]-[12].

In addition, the technologies of their creation have a number of disadvantages:

– production of loose backfills requires necessary technical skills and appropriate qualification of toolpushers, often violating the requirements of regulatory documents;

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– significant time costs for transporting gravel material from the day surface to the aquifer zone;

– qualitative formation of gravel backfill requires complex surface and downhole equipment and tools, which increases the cost of works;

– stratification of the gravel material in terms of size, both in height and diameter of the gravel backfill;

– hang-up of gravel material on the transport route with the formation of plugs, which requires additional time for its elimination;

– formation of gaping voids in the gravel pack in the aquifer zone, leading to sanding of the well.

Downhole filters include shell and block filters, the use of which also has a number of significant disadvantages. Shell filters have increased hydraulic resistance. In the process of operation due to electrochemical reaction the shell filters are prone to rapid contamination [13], [14]. During descent they are deformed, which leads to formation of uneven gravel layer thickness, and sometimes to formation of open channels and cavities.

In block type filters, the gravel bedding is bound with various binding agents. These blocks are placed on perforated support frames and lowered into the well as a complete unit.

V.M. Havrylko [15] formulated the requirements that block-type gravel filters must meet. Namely:

– since the blocks that are put on the filter column frame are loosely attached to the pipe surface and, therefore, perceive mining and filtration pressure, they must maintain the required strength or reduce it so that the residual strength is sufficient during the service life of the structure, which depends on the intended purpose of the well;

– binding agents must be resistant to corrosion and erosion, which inevitably occur when filtering water of different chemical composition;

– block filters must have sufficient pore size and effective porosity to ensure the required water flow to the well;

– binding agents used in gravel filters should not contain chemical components harmful to human health.

Unfortunately, to date, gravel filters of block construction do not meet the above requirements.

Block filters should not be subjected to shock loads that cause the structure of the blocks to break. In the manufacture of gravel blocks, binding agents should be used in such quantities that only gravel grains are bonded while maintaining the required effective porosity. In practice, block filters have lower permeability and higher hydraulic resistance compared to loose gravel consisting of grains of the same mechanical composition. The introduction of binding agents leads to a decrease in the effective porosity and a reduction in the size of the pores formed in the block body [16]-[20]. This is due to the complete overlap of a number of filtration channels with glue or their narrowing. In addition, various adhesives are used as binding materials in block filters that do not meet the requirements of sanitary standards and regulations for drin-king water supply wells.

To solve this problem, it is necessary to search for new technologies for the creation of gravel filters based on other physical processes and binding materials. New technological processes for creating gravel filters can include methods based on the use of the effect of the two-phase inverse transition of the aggregate state of the binding agent.

In Ukraine, in the context of current trends in climate change, significant anthropogenic impact, catastrophic floods, and radiation contamination of the territory, surface waters and productive horizons lying in the interval of 0-200 m are contaminated and unsuitable for drinking water supply [21]-[24]. Unfortunately, in most of Ukraine, water is supplied to the population from water supply intakes. Due to the deterioration of their equipment, the water does not meet sanitary standards and regulations. In addition, in a number of regions, there is a problem of creating hydrogeological wells for both drinking and technical water supply. In this regard, there is a significant shortage of drinking groundwater in Kyiv, Dnipro, Zaporizhzhia, Odesa, Kherson, Mykolaiv and other regions of Ukraine [25].

In the southern regions of Ukraine, about 300 settlements use partially or completely imported drinking water, including:

– in Odesa region (mainly in the south-west) – 80 settlements;

– in Mykolaiv region (in the north and central part) – 180 settlements;

– in Kherson region (in the north) – 70 settlements.

This problem can be solved by drilling hydrogeological wells intended for drinking and technical water supply of settlements. Currently, Ukraine has accumulated some experience in supplying drinking water to urban populations. More than 170 hydrogeological wells have been drilled and equipped in Kyiv and Odesa. However, in most cases, their depth, i.e. the depth of drinking water extraction, does not exceed 150-170 m.

Today, sources of clean drinking water are located much deeper, at depths of more than 200 m [6]-[10]. Under difficult mining and geological conditions, traditional block and casing filters do not work, as they have high hydraulic resistance and quickly clog during operation. Therefore, there is a need to drill and equip the water intake parts of the production hydrogeological well with reliable downhole drinking water treatment systems when organising alternative water supply for the population of Ukraine.

For two decades, the staff of the Department of Oil and Gas Engineering and Drilling of Dnipro University of Technology has been working on the development of technologies for the construction of gravel filters on the bottom surface and their equipment in the productive part of the well. During this time, extensive experience has been gained in developing technologies and implementing their results in production. Over this period of time, technologies for equipping hydrogeological wells with gravel filters have been developed [26]:

– filters with removable casing;

– block cryogenic gravel filters;

– block ceramic-gravel filters;

– cup-type filters.

The results of the work found practical application in Ukraine in the equipment of hydrogeological wells in the conditions of commercial enterprises PE “Azovnerudheolohiia” and LLC “Industrial Geological Group “Dniprohidrobud” [27]-[30].

In order to expand the field of application of effective technology for arranging deep wells with block-type filters (up to a depth of more than 200 m), the development and research of fundamentally new technologies for the production and equipment of productive horizons are necessary.

Therefore, the aim of the work is: scientific substantiation of technologies for the manufacture and equipment of block-type inverse gravel filters for the water intake part of deep hydrogeological wells for drinking water supply to the population of Ukraine, the productive horizon of which is represented by medium-grained, fine-grained and silty sands.

To achieve this goal, it is necessary to solve the problem associated with modeling the process of two-phase inverse transition of the aggregate state of the binding agent of an inverse block-type gravel filter during well construction.

2. Methods

The work performed by the authors is based on the idea of creating a technology for manufacturing a gravel filter element of a block structure with the connection of gravel material into a monolith using a water-based binding agent using cryogenic technology, followed by its installation in a well and the transition of gravel material from a monolithic state to a loose state due to the acquisition of rheological properties of water by the binding agent under the influence of formation water [31], [32].

A large number of studies have been concerned with modeling the processes of freezing or thawing rocks [25]-[33]. Studies of the freezing and deformation of rocks and porous materials are of practical interest. However, the aspects rela-ted to inverse gravel filters (IGFs) are not considered in these mathematical models.

The peculiarities of mathematical modeling of heat transfer processes during freezing and thawing of IGF, as well as the technological aspects that determine the problem statement, are considered in [33]-[36], which also presents the results of modeling the process of manufacturing a cryogenic gravel filter in the form of temperature fields in the filter element and shows the adequacy of this model. The modeling of heat and moisture transfer during the manufacture of a cryogenic gravel filter and its thawing during its transportation along the wellbore was carried out in [37]-[40].

The two-phase inverse transition of the aggregate state occurs when the liquid filling the pores and spaces between the particles of the filter media reaches the temperature of the corresponding phase transformation. For binding agents based on aqueous solutions, this temperature ranges from 0 to 3°C, depending on the chemical composition of the solution. When the filter is immersed in the well, heat is exchanged between the filter surface and the surrounding wellbore fluid. The intensity of heat exchange depends on the design parameters, immersion speed, physical properties of the fluid, the condition of the filter surface, etc. IGFs are a multiphase and multicomponent porous system, which in general consists of a skeleton (gravel), air and water. The mechanism of heat and moisture transfer in such systems has its own specific features related to the porous structure of IGF. Porous materials are characterized by a number of parameters, the combination of which gives a detailed picture of the properties of such materials. These parameters include the size and shape of the material grains, porosity, pore distribution over the body volume, and filtration characteristics of the porous material.

The IGF is a structure consisting of a filter column with cylindrical hollow polymer-gravel elements of a block filter, with a binding agent in the pore space of the material. The IGF consists of several blocks. The material of the polymer-gravel element is fine gravel. Based on this, we will make several assumptions for physical and mathematical modeling. We neglect the deformation processes in the composite during freezing, as well as the amount of water that remains unfrozen. We assume that the phase transformation process occurs within a narrow temperature range. To describe it, we use the experimental ice-content function.

Thus, the phase transformation process can be influenced by a significant number of factors, therefore, it is advisable to model the phase inversion transition in filters under certain physical assumptions that will greatly simplify calculations but will not fundamentally affect the physical picture of the process.

To model the thawing processes, we will proceed from the following assumptions. The gravel filter is represented as a cylindrical sample, which is a coarse medium (sand) with a frozen filler (water).

At the initial moment of time, the filter is immersed in the downhole environment and the process of convection heat exchange with the environment with a temperature higher than the phase transition temperature begins on its surface. It is assumed that the ambient temperature remains constant throughout the heat transfer process. In the first approximation, when constructing the mathematical model, we will neglect the effect of moisture transfer on heat transfer.

3. Results and discussion

The filter is immersed at a constant speed. At the same time, the filter body is unevenly covered by the fluid flow, so the heat transfer intensity is not the same on the side and end surfaces of the structure. To determine the heat transfer coefficients that occur during the transportation of the filter in the well, it is necessary to solve the hydrodynamics problem. To model hydrodynamic processes, the system of Navier-Stokes equations describing the motion of a viscous fluid is usually used. Today, there is no analytical solution to this system in the general case. Therefore, it is necessary to use numerical methods. In this work, we used the ANSYS Fluent software package for modeling hydrodynamic processes, which is focused on the numerical solution of hydrodynamics and heat transfer problems. The geometric characteristics of the filter and the well, the filter drawdown rate, the temperature, and the physical characteristics of the fluid (water) in the well were set as input data for computer modeling.

The hydrodynamic pattern that occurs when the filter is immersed in the well is shown in Figure 1. The descent rate is assumed to be 1 m/s. As can be seen from Figure 1, the speed reaches its highest values in the gap between the filter casing and the wellbore wall, where the maximum heat transfer intensity should be expected. The maximum pressure occurs in front of the filter. From the hydrodynamic point of view, a gravel filter is a poorly flowing body, which means that recirculating vortex flows of low intensity are formed behind the filter, creating additional bottom resistance. In general, the hydrodynamic picture shown in Figure 1 indicates that the modeling of transport processes in the filter body can be limited to a one-dimensional model. Consequently, we consider the thermophysical processes only in the radial direction of negligible heat transfer in the direction parallel to the cylinder axis. Thus, we have limited ourselves to an eight-symmetric formulation of the problem in the spatial coordinate.

Since the body of the gravel filter is a porous system, porosity is an important characteristic that affects the thermal and physical characteristics of the medium:

$$P = \frac{V_p}{V},$$

where:

V_p – a pore volume;

V – a total body volume.

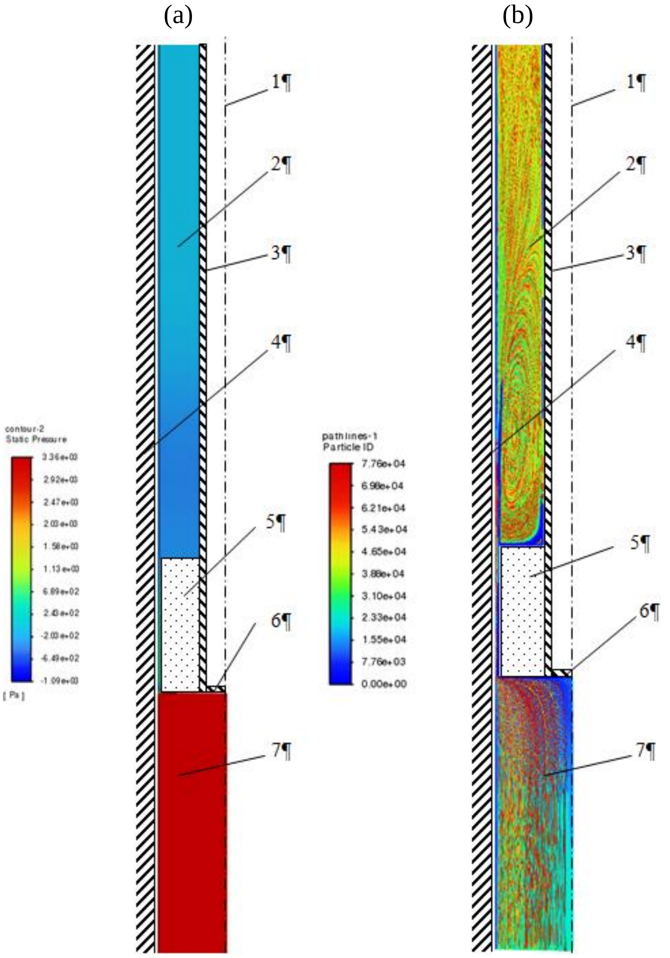


Figure 1. Hydrodynamic fields at the flow of an inverse gravel filter in a well: (a) statistical pressure field; (b) pattern of current lines; 1 – well axis; 2 – well fluid above the IGF; 3 – drill pipe string; 4 – well wall; 5 – IGF; 6 – filter string "shoe"; 7 – well fluid under the IGF

To determine the effective thermal conductivity coefficient, taking into account the porosity of the system, we use the following relations [41]-[43]:

$$\lambda_e = \lambda_1 \left[\frac{5.8(1-P)^2}{K} \left(\frac{1}{K} \ln \frac{\lambda_2}{\lambda_1} - 1 - \frac{K}{2} \right) + 1 \right], \quad (1)$$

where:
$K = 1 - \lambda_1 / \lambda_2$;
λ_1 – the thermal conductivity of the "skeleton";
λ_2 – the thermal conductivity of the frozen dispersed component (binding agent).

The effective heat capacity is an additive value and to determine it we use:

$$c_e = (1-P)c_s + P \cdot c,$$

where:

c_s – a heat capacity;

c – "skeleton", heat capacity of the frozen dispersed component (binding agent – ice).

To determine the heat transfer coefficient α during the transportation of the filter through a column of pipes, we use the expression for determining α of a vertical hollow cylinder under forced convection. Reynolds number:

$$\text{Re} = \frac{w\delta}{\nu},$$

where:

w – the filter descent rate;

ν – the coefficient of kinematic viscosity of water;

δ – the thickness of the annular gap between the filter walls and the well walls.

The criterion equation for the heat transfer coefficient in this case is [41], [43]:

$$Nu = 0.24 \cdot \text{Re}^{0.34} \cdot \text{Pr}^{0.33} \cdot \left(\frac{\text{Pr}}{\text{Pr}_w} \right)^{0.25}, \quad (2)$$

where:

$Nu = \alpha\delta / \lambda_l$ – a Nusselt criterion;

$\text{Pr} = a / \nu$ – a Prandtl number;

λ_l – a thermal conductivity coefficient;

α – a heat transfer coefficient.

The index "w" means that this criterion is calculated based on the temperature of the filter wall, while the rest of the coefficients are calculated based on the average temperature of the water and filter. Thus, the heat transfer coefficient is determined by:

$$\alpha = \frac{Nu}{\delta} \lambda_l .$$

The filter column has a closed shoe. The inner surface of the filter is therefore only in contact with the filter column. Therefore, the heat transfer on the inner surface can be neglected and the thermal insulation condition can be used.

Given that the onset of filter failure is determined by the temperature of the inverse transition, we will consider the problem only until the time when the temperature of the side surface reaches this value. We assume that there is almost no heat transfer on the inner surface of the cylindrical body.

In general, the mathematical model of the filter body thawing process is described by the unsteady-state heat transfer equation in a cylindrical coordinate system with the corresponding boundary and initial conditions:

$$c_e \rho \frac{\partial t}{\partial \tau} = \frac{1}{r} \cdot \frac{\partial}{\partial r}\left(\lambda_e r \frac{\partial t}{\partial r} \right) + \frac{\partial}{\partial z}\left(\lambda_e \frac{\partial t}{\partial z} \right); \quad (3)$$

$$0 < r < R, \quad 0 < z < H, \quad \tau > 0.$$

$$\lambda_e \left. \frac{\partial t}{\partial r} \right|_{r=R} = -\alpha_1 \left(t|_{r=R} - t_w \right), \qquad \left. \frac{\partial t}{\partial r} \right|_{r=R_i} = 0 . \quad (4)$$

$$\lambda_e \left. \frac{\partial t}{\partial z} \right|_{z=0} = -\alpha_2 \left(t|_{r=R} - t_w \right);$$

$$\lambda_e \left. \frac{\partial t}{\partial z} \right|_{z=H} = -\alpha_3 \left(t|_{r=R} - t_w \right); \quad (5)$$

$$t|_{\tau=0} = 0, \quad (6)$$

where:

R – the outer radius of the filter;

R_i – the inner radius of the filter;

τ – the time;

H – the filter height;

α_1, α_2, α_3 – the heat transfer coefficients on the side, lower end, and upper end surfaces, respectively.

We assume that the initial temperature is known and homogeneous along the radius, and the ambient temperature is also constant.

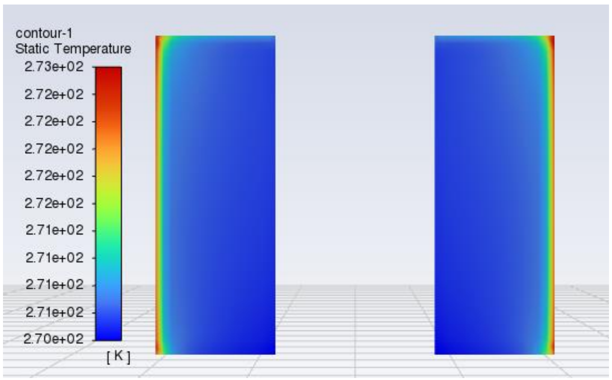
3.1. Computer modeling of heat transfer processes in an inverse gravel filter during transportation in a well

The mathematical model (3)-(6) proposed above was implemented to study the thermal state of the gravel filter. Numerical studies were carried out using the Ansys Fluent (student) software package. The Ansys software component is a universal software system for finite element analysis, which is designed for engineering based on the finite element solution of linear and nonlinear, stationary and unsteady problems of solid, liquid, and gas physics.

The initial data were taken as R_1 = 0.05 m, R_2 = 0.125 m, h = 0.2 m, the initial temperatures of the inverse gravel filters were 90, 50 and 20ºC, and the water temperature was 5 ºC. The density of the frozen sand is constant at 2260 kg/m^3, the thermal conductivity at 22% porosity is 4.5 W/m K, at 10% – 3.7 W/m K, at 5% – W/m K. Heat transfer coefficients: for the outer wall of the cylinder 300 W/m^{2}K, for the upper surface of the cylinder 50 W/m^2 K, for the lower surface of the cylinder 0.5 W/m^2 K.

The results of modeling the temperature state in the axial section for the above conditions are shown in Figure 2. From Figure 2 it can be seen that the temperature field perturbation occurs only in a thin layer bordering the side surface of the filter. Since the flow velocity is maximum in the annular gap between the filter and the well wall, convection heat transfer of maximum intensity occurs on the side surface.

(a)



(b)

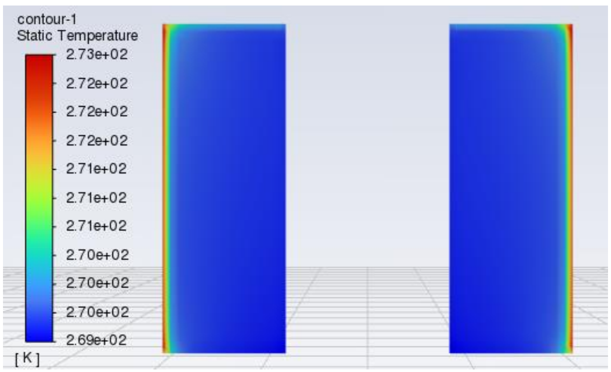


Figure 2. The temperature field of an inverse gravel filter with thermal conductivity of: (a) 4.5 W/(m^2·S) at an initial temperature of 90ºC for 470 s; (b) 2.2 W/(m^2·S) at an initial temperature of 90ºC for 470 s

It should be noted that despite the fact that the porosity of the medium (in the considered range of 5-22%) affects the thermal conductivity, the final thawing time (the time for which the temperature reaches the value of the corresponding phase transition on the surface) does not change significantly for the same initial temperature.

The initial temperature is the determining parameter that affects the melting time. Figure 3 shows the change in the surface temperature of the gravel filter for different values of the initial temperature.

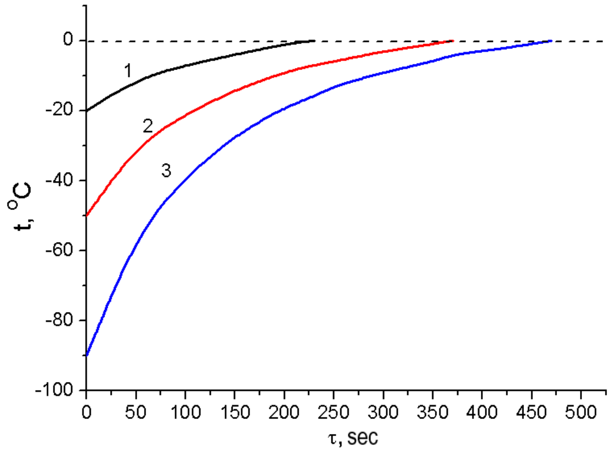


Figure 3. Temperature change on the filter surface over time for different values of the initial temperature: 1 – -20ºC; 2 – -50ºC; 3 – -90ºC

The temperatures considered range from low (-20ºC) to cryogenic (-90ºC). As can be seen from Figure 3, a decrease in the initial temperature from -20 to -90ºC can more than double the thawing time.

3.2. Analytical modeling of heat transfer processes in an inverse gravel filter during transportation along a wellbore

The results of computer modeling of the gravel filter melting processes confirm the possibility of using a one-dimensional model to calculate the heat transfer process in the filter. In this case, we can develop a methodology for calculating the simulation of the process of two-phase inverse transition of the aggregate state of the binding agent during the transportation of inverse gravel using an analytical solution to the heat conduction problem.

Let us limit ourselves to the radial coordinate in models (3)-(6). Thus, the equation of the heat transfer process under the assumptions made will be written in the form:

$$\frac{\partial t}{\partial \tau}=\frac{a_e}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right),\quad 0<r<R,\quad \tau>0\,, \tag{7}$$

where:

$a_e = \lambda_e / c_e{\cdot}\rho$ – the effective thermal conductivity coefficient of the filter medium.

Convection heat exchange with the medium occurs on the outer surface of the filter, while on the inner surface of the body we assume no heat exchange. Thus, the boundary conditions for (7) are written as:

$$\lambda_e \left.\frac{\partial t}{\partial r}\right|_{r=R}=-\alpha\left(t\big|_{r=R}-t_w\right),\ \left.\frac{\partial t}{\partial r}\right|_{r=R_i}=0\,. \tag{8}$$

The thermophysical characteristics and heat transfer coefficient in Equations (7)-(8) are determined using Expressions (1)-(3). The initial temperature of the sample is known and uniform along the radius:

$$t(r,0) = t_0 = const. \quad (9)$$

Problem (7)-(9) is a linear heat conduction problem and can be solved analytically using the Fourier method [43], [44]. The analytical solution to problems (7)-(9) is as follows:

$$\frac{t(r,\tau)-t_0}{t_w - t_0} = 1 - 2\sum_{n=1}^{\infty} \frac{Bi^2}{\mu_n^2 + Bi^2} \frac{J_0(\mu_n r)}{J_1(\mu_n)} \cdot \exp(-\mu_n Fo), \quad (10)$$

where:

$Bi = \alpha R / \lambda_e$ – the Biot number;

$Fo = \tau a_e / R^2$ – Fourier criterion;

J_0, J_1 – Bessel functions of the 1st kind of zero and first order, respectively.

The values of the eigenvalues μ_n are determined by solving the transcendental equation:

$$\frac{J_0(\mu)}{J_1(\mu)} = \frac{\mu}{Bi}.$$

The solution in the form of (10) is effective for $Fo > 0.3$. In practice, in the case of gravel filter thawing, the Fourier numbers may be $Fo < 0.3$. In this case, it is necessary to use a significant number of terms in the series in (10), which is not rational for the estimated calculation. From the nomogram [42], constructed from the solution of the heat conduction equation, which allows us to estimate the temperature on the surface of the cylinder for a wide range of defining numbers *Fo*, *Bi*.

Let's consider using the analytical calculation method to determine the temperature on the surface of a gravel filter.

The initial data for the calculation are the same as in the case of computer modeling: $\alpha = 300$ W/m^{2}K; $R = 0.125$ m; $\lambda = 4.5$ W/m·K (corresponds to $P = 22\%$); $s = 880$ J/kg·K; $\rho = 2260$ kg/m^3. If we assume a thawing time of 470 s, the corresponding dimensionless parameters are:

$Fo = 0.01$; $Bi = 8.3$.

From the solution of (10) we obtain:

$$U = \frac{t(r,\tau)-t_0}{t_w - t_0} = 1 - 2\sum_{n=1}^{\infty} \frac{Bi^2}{\mu_n^2 + Bi^2} \frac{J_0(\mu_n r)}{J_1(\mu_n)} \times$$

$$\times \exp(-\mu_n Fo) = 0.91.$$

$$t = t_0 + (t_w - t_0) \cdot U = -3.55\ °\text{C},$$

which coincides with the result of computer modeling, according to which the temperature on the filter surface is equal to 0°C, with an accuracy of 4%.

Table 1 shows the results of a comparative analysis of the calculation of the melting time using the analytical method and the numerical method for solving the problems of melting a porous dispersed water-saturated medium.

Table 1. Calculation of the thawing time of a porous dispersed water-saturated medium during transportation along the wellbore

Thawing time	Initial temperature, °C		
	-90	-50	-20
ANSYS	470	370	220
Analytical method	492	388	231

The results of Table 1 indicate a good correlation between the results of computer modeling and the analytical calculation methodology.

The theoretical study of the process of two-phase inverse transition of the aggregate state of the binding agent of the polymer-gravel element of the block-type inverse gravel filter confirmed the possibility of its transportation along the wellbore and arrangement of its water pressure formation.

The modeling took into account the design features of modern drilling equipment. The parameters of the transportation mode of the block-type inverse gravel filter were in the ranges provided by the technical characteristics of the drilling equipment, taking into account the well diameters. The results of the theoretical studies will be confirmed during the pilot testing of the technology.

Pilot tests of the water treatment technology for deep hydrogeological wells will be carried out in the conditions of existing hydrogeological wells at the sites to be determined during the scientific and technical work.

The results of scientific and technical work will make it possible to obtain sources of high-quality drinking water. The cost of technological operations compared to traditional well construction technologies, according to preliminary implementation data, per operation is reduced by $500. USA with a well up to 100 m deep. The economic efficiency from the implementation of the proposed technology will be many times greater due to the reduction in the need to drill new hydrogeological wells. The social effect consists of creating new jobs, raising living standards of the population, and improving the health of the nation.

4. Conclusions

A mathematical model of the processes of polymer-gravel element of IGF thawing during its transportation along the wellbore has been developed. A methodology for modeling the process of two-phase inverse transition of the aggregate state of the binding agent during the transportation of an inverse gravel filter of block type in the course of well construction has been developed.

The results of mathematical modeling of the process of two-phase inverse transition of the aggregate state of the binding agent of an inverse block-type gravel filter during well construction show that during the transportation of the filter, a relatively rapid hydrodynamic flow occurs in the annular space between the walls of the well and the filter. As a result, intense convection heat transfer occurs on the filter surface, which leads to the filter surface thawing. The thawing time is insignificant compared to the filter transportation time and depends on the initial temperature of the filter. This time is 3.5 minutes at an initial temperature of -200°C to 8 minutes at an initial temperature of -900°C. The porosity of the filter media does not have a significant effect on the thawing time. Thawing occurs only in the thin layer of the filter near the surface.

The results of calculating the time of thawing of a porous dispersed water-saturated medium during transportation along the wellbore indicate a good correlation between the results of computer modeling and analytical calculation methods.

Based on the results of the work, a methodology for determining the temperature and time parameters of the process of two-phase inverse transition of the aggregate state of the binding agent of an inverse block-type gravel filter during well construction is proposed.

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Визначення теплового стану блочного гравійного фільтру, під час його транспортування по стовбуру свердловини

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Мета. Розробка методики визначення теплового стану блочних інверсних гравійних фільтрів, що виготовлені за низькотемпературною технологією, під час їх транспортування в свердловині, на основі комп'ютерного і математичного моделювання.

Методика. Дослідження гідродинамічних процесів, що мають місце під час транспортування фільтру в свердловині, а також розрахунок теплових полів в тілі фільтру виконано із використанням програмного комплексу Ansys Fluent. Визначені ефективні теплофізичні характеристики фільтру, застосовані підходи теорії теплопереносу в пористих середовищах. Для дослідження теплових режимів фільтру під час теплообміну зі свердловинною рідиною запропоновано використання аналітичного розв'язання задачі теплопровідності в циліндричній оболонці з урахуванням властивостей пористого дисперсного водонасиченого середовища.

Результати. Розроблено методику розрахунку теплового стану гравійного фільтру під час його спуску в свердловині. Для оцінки температури поверхні фільтру запропоновано вираз, що отриманий на основі аналітичного розв'язання рівняння теплопровідності з урахуванням характеристик пористого середовища фільтру. Отримані гідродинамічні та теплові поля в свердловині і тілі фільтру під час процесу транспортування фільтру в свердловині.

Наукова новизна. Вперше розглянуто задачу теплообміну гравійного інверсного фільтру, що виготовлений за низькотемпературною технологією, в свердловині. Показано вплив гідротермічних умов в свердловині на процес нагрівання фільтру під час його транспортування в свердловині. Встановлено гідродинамічні поля при обтіканні буровим розчином інверсного гравійного фільтру.

Практична значимість. Запропоновані підходи і результати дослідження дозволяють визначати і можуть бути використанні при розробці технологічного регламенту використання блочних гравійних фільтрів, що виготовляються за низькотемпературною технологією, для обладнання гідрогеологічних свердловин. Розроблено методику моделювання процесу двофазного інверсного переходу агрегатного стану в'яжучої речовини при транспортуванні інверсного гравійного фільтру блокового типу при спорудженні свердловини.

Ключові слова*: свердловина, в'яжуча речовина, гравійний фільтр, температурне поле*