УДК 536.24

A. Khaminich, K. Heti, O. Matyash

Oles Honchar Dnipro National University

CALCULATION OF TEMPERATURE MODES OF GRAIN FILTERS MANUFACTURED BY LOW TEMPERATURE TECHNOLOGY AFTER DEFROSTING

Розроблено методику моделювання теплофізичних процесів у гравійних фільтрах, виготовлених по низькотемпературній технології, та досліджено період початку фазового переходу на поверхні фільтру в залежності від експлуатаційних умов.

Ключові слова: гравійний фільтр, фазовий перехід, математична модель, дисперсне середовище, розморожування

Разработана методика моделирования теплофизических процессов в гравийных фильтрах, изготовленных по низкотемпературной технологии, и исследован период начала фазового перехода на поверхности фильтра в зависимости от эксплуатационных условий.

Ключевые слова: гравийний фильтр, фазовый переход, математическая модель, дисперсная среда, размораживание.

The method of thermophysical processes simulation in gravel filters made by low-temperature technology was developed, and the period of the beginning of phase transition on the filter surface depending on the operating conditions was investigated.

Keywords: gravel filter, phase transition, mathematical model, dispersion medium, defrosting.

A series of works is devoted to the mathematical modeling of heat transfer problems in dispersed media in the presence of phase transitions. The practical interest of such kind of problems has investigation of soil freezing, drying of capillary-porous materials, filtration tasks, and others. In particular, the actual task is to determine the parameters of manufacturing and operation of gravel filters made by low-temperature technology (or cryogenic-gravel filters).

According to this technology the required structural strength is achieved by the phase transformation of a binder fluid, which uses water or a solution thereof. Then when installing such a block of filter in the well a reverse phase transition of the binder fluid occurs. As a result we obtain a filter whose filtration characteristics meet the technological requirements.

Among the factors that affect the effectiveness of filters made by low-temperature technology, we distinguish the physical characteristics of the filter material and the adhesive fluid, external and operating conditions.

One of the important physical characteristics of the bulk material of the filter is its voidness, that is, the presence of cavities (voids) between the grains of the material. Obviously, in order to determine the influence of the physical characteristics of the environment on the technological parameters of the manufacture and operation of such filters, it is necessary to study the processes of heat transfer in the filter environment. The study of such processes can be accomplished using mathematical modeling methods, since the use of these methods is well understood today and is most appropriate for solving such a class of problems.

From a physical point of view, a gravel filter is a multiphase and multicomponent system, which consists of a mineral component - gravel and a dispersion medium - water. The dispersion environment, based on the technology of well equipment, is in the prepared period in a solid state, and with an increase in the temperature of the phase transition - in liquid.

To construct a mathematical model, imagine that a gravel filter (GF) is a limited, empty cylinder made of coarse porous material (sand). As a binder filler we will consider the water. Suppose that the heat exchange with the environment in the case of defrost meets the conditions of free convection. Then we will assume that the phase transition for this system of ice - water almost completely occurs at a temperature of 0 ° C, which is confirmed by experimental data. In general, this problem should be considered together with the moisture transfer, but for long processes under atmospheric pressure in the first approximation, the mutual influence of the thermal field and the field of moisture can be neglected.

To deliver the monolith of the gravel filter to the working position, it is necessary to perform operations for preparation and descaling, in which the defrosting of the filter takes place. To ensure a sufficient strength of the filter design and to prevent premature destruction, it is necessary to know the start time of the phase transition on the filter surface, depending on the operating conditions. To determine the time parameters of the destruction of the filter it is necessary to solve the problem of heat transfer in a porous water-saturated medium of a gravel filter in the presence of a phase transformation of the binder.

To solve the problem of defrosting the dispersed environment of a gravel filter, we use the mathematical model of heat transfer in a dispersed water-saturated medium in the presence of phase transformation.

The differential equation of heat transfer in the GF in the presence of a phase transition will be written using the effective heat capacity:

$$c_{ef}\left(T\right)\rho\left(T\right)\frac{\partial T}{\partial \tau}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\cdot\lambda\left(T\right)\frac{\partial T}{\partial r}\right) \qquad (1)$$

$$\tau \succ 0,\quad R_1 \le r \le R_2,$$

where c_{ef} – effective heat capacity of the dispersed medium, $\rho(T)$ – the density of the dispersed medium, $\lambda(T)$ – the coefficient of thermal conductivity of the GF,

T – the temperature of the filter, τ – the time, R_1, R_2 – the internal and external radiuses of the filter (Fig.1).

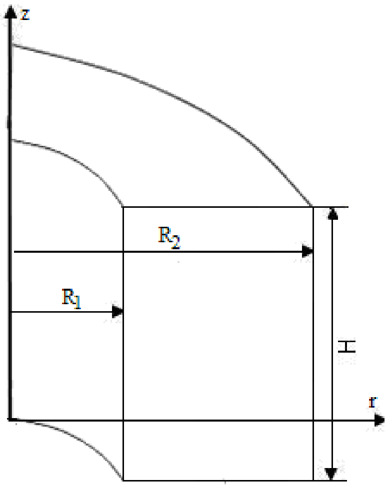

Fig. 1. Estimated area

With uniqueness conditions that match the defrost mode we obtain:

$$T\big|_{\tau=0} = T_0, \tag{2}$$

$$\lambda(T)\frac{\partial T}{\partial n}\bigg|_{n=s} = \alpha_s\left(T - T_\infty\right) \tag{3}$$

where n – external normal to the surface, α_s – coefficient of heat transfer with the environment s-th surface of the filter wall, T_∞ – air temperature on the surface of the well.

The average coefficient of heat transfer $\overline{\alpha}$ during the operation of the GF is changing, according to the technology of GF operation, where are three modes of defrosting the filter:

- preparatory work in the air, then the coefficient of heat transfer is determined according to the conditions of free convection in an unlimited space;
- when the drill string is raised, the filter is stationary in the well, the environment is water in a closed space;
- descent of the GF along the wellbore, the heat exchange with the environment meets the conditions of forced convection in a closed space.

The values of heat dissipation were taken from literature in an arbitrary order from 9 to 70 W / m^{2}K.

To provide the required strength of a gravel filter design, the determining parameter is the start time of the phase transition of the reinforcing material to the surface of the filter wall. Then, to simplify the calculation model, the transfer of moisture in the frozen wall is neglected.

We write the effective heat capacity in (1) as follows

$$c_{ef}(T)=(1-m)c_{sk}+m\cdot(1-i(T))\cdot c_w\cdot U+m\cdot i(T)\cdot c_l\cdot U+\frac{\rho_l}{\rho(T)}\cdot m\cdot l\cdot\frac{di}{dT} \tag{4}$$

where $i(T)$ – the function of ice, m – porosity, l – specific heat of the phase transition, c – heat capacity, ρ – density, indices sk, w, l refer to the skeleton, water, ice, respectively.

Nowadays there are various approximate analytical and numerical methods for solving heat transfer problems in dispersed media with phase transitions. To solve the mathematical model of GF we used a numerical method.

From a mathematical point of view our task of defrosting the GF was reduced to solving a one-dimensional problem, that leads to the solution of the nonstationary equation of heat conductivity:

$$c_{ef}(T)\rho(T)\frac{\partial T}{\partial\tau}=\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\lambda(T)\frac{\partial T}{\partial r}\right) \tag{5}$$

$$\tau\succ 0,\quad R_1\le r\le R_2 \tag{6}$$

with initial temperature

$$T(x,z,0)=T_0=const \tag{7}$$

at the following boundary conditions:

$$\lambda(T)\left.\frac{\partial T}{\partial r}\right|_{r=R1}=\bar{\alpha}\left(T|_S-T_\infty\right), \tag{8}$$

$$\lambda(T)\left.\frac{\partial T}{\partial r}\right|_{r=R2}=-\bar{\alpha}\left(T|_S-T_\infty\right). \tag{9}$$

During the preparatory operation the blocks of gravel filter are located on the surface of the well at ambient temperature.

The results of numerical simulation of GF warming during defrosting of the air filter are shown in the drawings.

We construct graphs of temperature distribution along the radius of the filter, depending on the time from the beginning of defrost up to 2 hours (Fig.2).

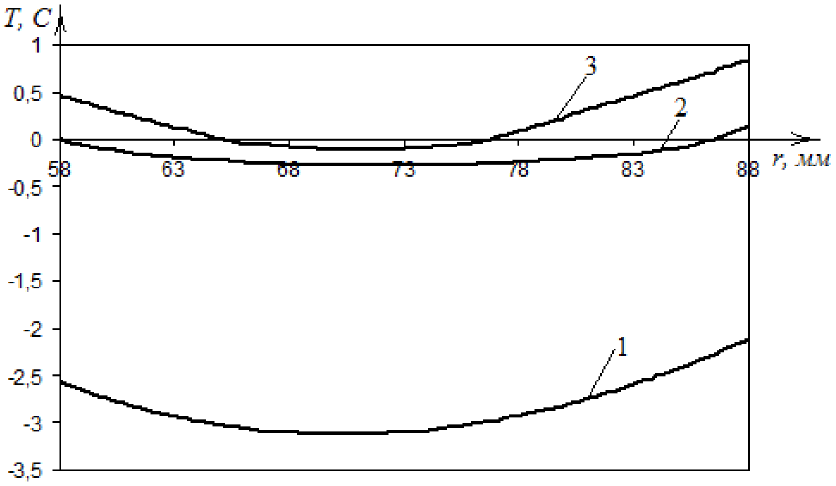

Fig. 2. Distribution of temperature in the radius:
1 - 1 hour, 2 - 1,5 hours, 3 - 2 hours.

The greatest temperature gradients arise at the initial stage of the defrost of the filter, that is, at the heating stage of the region. 50 minutes after the start of defrost, a phase transformation is observed on the surface of the filter wall, and after 2 hours, the phase transition phase is already in the middle of the filter wall.

The second step will be to investigate the influence of the initial and external conditions on the process of defrosting the block of gravel filter.

We construct a graph of the temperature field dynamics in the middle of the filter wall (Fig.3).

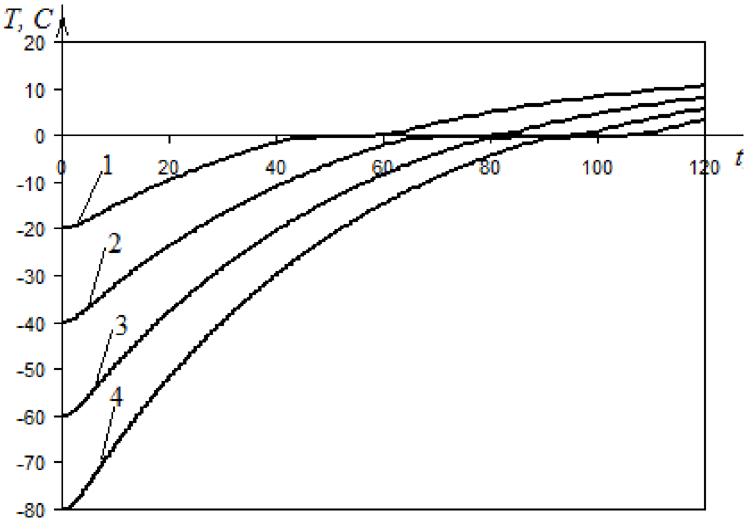

Fig.3. Dynamics of the temperature field in the middle of the filter wall:
$T_\infty = 15^0 C$, $U_0 = 10\%$, $T_0 = -20^0 C$ **(1),** $-40^0 C$ **(2),** $-60^0 C$ **(3),** $-80^0 C$ **(4).**

With the decrease of the initial temperature of the gravel filter, the temperature in the middle of the filter wall varies according to the graph (Fig. 4), the phase of the start of the phase transition increases, the phase transition period decreases.

Imagine the effect of ambient temperature on the dynamics of the defrosting process of the test element.

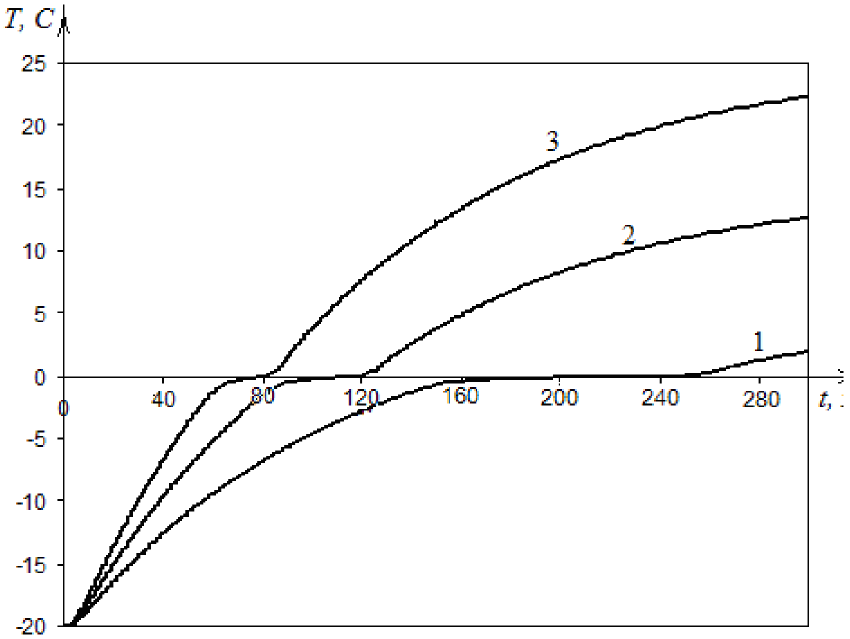

Fig. 4. - Dynamics of the temperature field in the middle of the filter wall, $T_0 = -20^0 C$**,**

$U_0 = 10\%$**,** $T_\infty = 5^0 C$ **(1),** $15^0 C$ **(2),** $25^0 C$ **(3).**

With the increase of the air temperature at a fixed initial temperature and humidity of the filter, the start time of the phase transformation is reduced.

In the following graph, the dependence of the beginning of defrosting on the outer surface of the gravel filter on the temperature of the air for the initial temperature of the filter $-20^0 C$, $-40^0 C$, $-60^0 C$, $-80^0 C$, $-100^0 C$ and the initial humidity 5% has been constructed. For example, at the initial temperature $-40^0 C$ of the fracture filter, it will start after $70\,\mathrm{sec}$ at air temperature $5^0 C$ and after $40\,\mathrm{sec}$ with air temperature $25^0 C$ (Fig. 5).

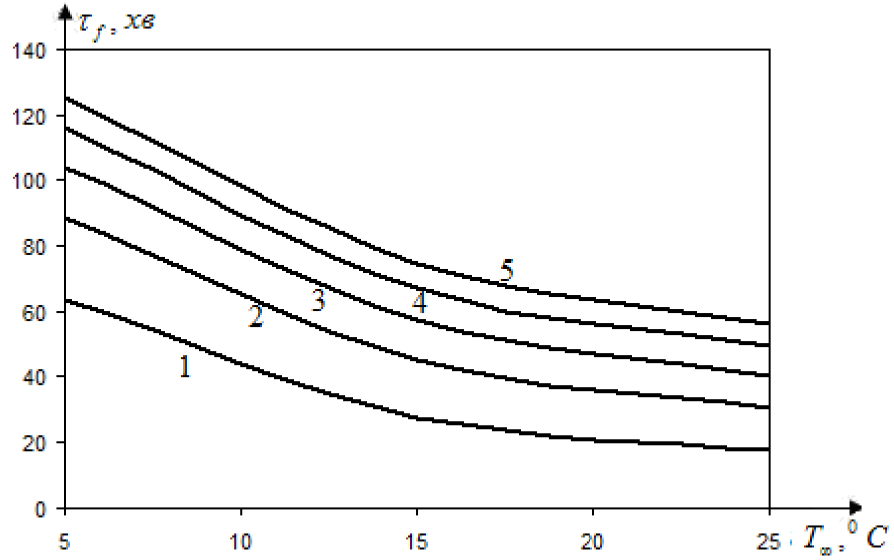

Fig. 5.The beginning of the destruction of the filter surface with the initial temperature of the gravel filter: $-20^0 C$ **(1),** $-40^0 C$ **(2),** $-60^0 C$ **(3),** $-80^0 C$ **(4),** $-100^0 C$ **(5).**

.

During the preparatory work on mounting gravel filters made by low temperature technology, the time interval for which the surface of the filter will begin to decay is determined depending on the temperature regime of the environment on the surface of the well, the temperature and humidity of the frozen filter.

The calculation results allow to determine the required time depending on the defrost conditions. An overview of methods for solving heat transfer problems in dispersed media with phase transitions is performed. The calculations of a one-dimensional non-stationary problem in the presence of a phase transition of ice-water for a dispersed water-saturated medium have been carried out. The time of the beginning of the phase transition on the filter surface, depending on the operating conditions has been investigated.

References

1. Goshovsky SV Analysis of technologies of equipment of the water receiving part of hydrogeological wells by means of graduated gravel filters with removable protective casing / AA Kozhevnikov, AK Sudakov, OA Grinyak // Seminar №19. - 2008. - pp. 287-289.
2. Kozhevnikov AA The technology of equipment for cryogenic-gravel filters of a water receiving part of a borehole. / AA Kozhevnikov, SV Goshovsky, AK Sudakov // Breeding and metal working tools, 2009. - Ex. 12. - pp. 62 - 66.
3. Kozhevnikov AA Geological and technical conditions of equipment for hydrogeological wells with cryogenic-gravel filters. / Dychakovsky R.E., Sudakov A.K. // Scientific works of DonNTU. Series "Mining and Geological". No. 1 (20) '2014. - pp. 80-88. ISSN 2073 - 9575.
4. Kozhevnikov AA About the Choice of Equipment Technology for Productive Horizons of Drilling Wells by Gravel Filters / Sudakov AK // 2011.- S. 356 - 361.
5. Nersesova Z.A. Changes in the soil's ice content, depending on temperature // DAN USSR. - 1950. - Vol. 75. - No. 6. - pp.845 - 846.
6. Permyak P.P. Identification of parameters of the mathematical model of heat transfer in frozen soils. - Novosibirsk: Science, 1989. - 86 p.