Calculation of the parameters of the technology of preparation of artificial sushenitsy

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Abstract. The article deals with the cases of conformal mapping of the region of the reduced complex potential of one-dimensional steady-state filtration to the area of gravity-free uniform filtration, which occurs in a permeable layer of peat when an incompressible activated reagent solution moves in a porous medium. On this basis, a methodology has been developed for calculating the parameters of the technology for the preparation of artificial sushenitsy (artificial coarse-grained rocks with small ice inclusions in artificial rocks) for stripping operations during the development of placer deposits.

1. Introduction
The technology for the preparation of artificial sushenitsy consists of two main elements: thawing frozen peat (usually by filtration and drainage method or using boreholes) and reducing the moisture content of sediments to a critical value (3.5%) by draining the thawed massif [1]. After that, the peat is ready for year-round development. The implementation of filtration and drainage thawing and the creation of artificial sushenitsy similar requirements on the composition and hydrophysical properties of peat. The filtration and drainage method of hydraulic defrosting differs from the needle one mainly in that the artificially fed filtration flow does not move vertically upwards, but horizontally, along the strata, under the influence of the natural slope. The length of horizontal filtration paths from the place of feeding to the outlet of water into a drainage mine or borehole can be 20 - 80 m. [2]. This distance is assigned depending on the specified final thawing depth, filtration properties of rocks and the permissible duration of work. A shorter distance provides more intense defrosting. In placer deposits, this method allows you to thaw layers of frozen pebbles or crushed stone, gravel, sand, undivided by weakly permeable interlayers (clay, loam or sandy loam).

2. Research methodology
In order to expand the field of application of this method, laboratory and later pilot-industrial studies were carried out on the preparation of artificial sushenitsy with a clay content of up to 15% in peat. The idea of the work was a method of preparation of sushentsovye zones with preliminary filtration in the mass of a placer of an activated reagent solution (APP) [3]. Reagents such as sodium aluminate, ferric chloride, Separan 2610 together with electrolytes, sodium silicate and high molecular weight polymers of the KODT type (condensation product of distillation residues of hexamethylenediamide, tall oil and dichloroethane) and others were used as the filtering liquid. Good results were obtained using ferric chloride.
The modified varieties of montmorillonite in the course of laboratory studies were obtained by appropriate treatment of montmorillonites with solutions of sodium chloride and calcium. Natural samples were subjected to compression corresponding to the pressure experienced by these samples in natural conditions. Studies of the effect of temperature on the permeability of clays were carried out on natural kaolin, montmorillonite and micaceous clays and their varieties using distilled water and a solution of ferric chloride of various concentrations. The duration of temperature activation was from 30 min. up to 1 day when heating the reagent to 60-80°C. Before increasing the temperatures, the samples were kept at a given pressure of the hydrocompression for 5 days. To eliminate the influence of temperature hysteresis, the samples were first subjected to repeated heating and cooling. The initial values of permeability (at room temperature) were taken as their constant values, which did not change after the next heating - cooling cycle. Upon subsequent heating of the reagent at each temperature point, the sample was kept for 1 day. The clay content varied from 3 to 15% [4]. At each stage of the action of the activated reagent solution on the samples, the filtration rate was recorded until the filtration flow rates were completely stabilized.

Under industrial conditions, the experiments were carried out at one of the Sakha placer deposits (Yakutia). The choice of the method of feeding the filtration flow (APP) was taken depending on the type of section, the thickness of frozen rocks, their thickness and the nature of the relief of the placer area. Drainage ditches were used at a given thawing depth of up to 6 m.

Control over the peat drying process was carried out by measuring the phreatic surface levels in piezometric wells. To determine the residual moisture content of peats, before the onset of severe cold weather, control ditches were passed with the selection and testing of samples. If the moisture content of the peat was less than critical, then the landfill was considered ready for year-round stripping operations.

Absorption boreholes were used at a thawing depth of up to 8 meters and the content of lenses of poorly permeable rocks in the peat strata.

A certain amount of silt always settles out of the water, which first forms an intermittent, low-permeable screen at the bottom and gradually leaves only separate passages in large pores for infiltration. In addition, thin silt clogs the gravel to a depth of 0.2 - 0.4 m. Therefore, the filtration ditch was located behind the outer contour of the thawing area. The depth of the water layer in the maximally filled ditch reached 1.5-2 m.

Drainage ditches 3 m wide were bulldozed with dumps at the end of each dead end. A number of horizontal drains during the first period of processing of the APP massif were located at a distance determined only empirically, which reduced the effectiveness of the measures taken. Subsequently, the front of the filtration flow feeding was transferred beyond the outer contour of the thawing area, where by this time new drainage ditches were being passed. The lack of a scientifically grounded methodology for calculating the parameters of the technology for the preparation of artificial sushenitsy (the distance between horizontal drains, the parameters of the grid of absorption wells, the duration of peat processing with APP, etc.) reduced the expected effect. This circumstance explains the relevance of scientific research, aimed at the development of theoretical foundations for the preparation of artificial sushenitsy in poorly permeable rocks based on their treatment with an activated solution of the reagent.

3. Research results
The implementation of the task is that the considered filtration flow of the region of the reduced complex filtration potential will be a rectilinear polygon on a plane with sides parallel to the coordinate axis OX. Having made a conformal mapping of the area of the reduced complex filtration potential, it will be possible to determine all the characteristics of the filtration flow, and, consequently, the required parameters of the technology for the preparation of artificial sushenitsy.

Filtration and drainage defrosting is the simplest way of defrosting in terms of its technological and organizational characteristics. In practice, filtration and drainage defrost is used at the required defrost depth not exceeding 5-6 meters, although the possibility of reaching a depth of 8 m has been proven. [6].
In the course of industrial experiments, it was found that, in addition to the distance between the drains, the duration of peat processing with APP, the depth of the drainage ditches also affects the rate and cost of filtration and drainage thawing.

It was found that with an increase in the distance between drainage ditches several times exceeding the thawing depth, the thawing rate becomes insufficient, which requires an increase in the depth of horizontal drains to 3m (with the thickness of the prepared layer of sushenitsy up to 6m).

In this case, two calculation options are considered. The first one provides that the peat massif is homogeneous with a uniform content of clay cement. The second one provides for a non-uniform clay content in peats (layered rocks).

During filtration and drainage thawing in a homogeneous mass of peat (the first variant of the calculation), there is a uniform steady filtration, in which the streamlines of the filtered activated reagent solution (APP) are parallel straight lines. With such filtration, the shape and dimensions of the flow area do not change along its length. Since the boundaries of the prepared polygon do not create special conditions for the resistance forces, the movement of the APP in the entire filtration area will be the same. The equation of such filtration has the form [5]

$$\frac{d^2 H}{dx^2} = 0,$$

where $H$ - head, m; $x$ - coordinates of the APP movement along the OX axis.

The piezometric slope or head gradient will be

$$J = \frac{dH}{dx} = \frac{H_1 - H_2}{L_f},$$

then

$$V = K_f \frac{H_1 - H_2}{L_f},$$

where $K_f$ - filtration coefficient, m / day; $V$ — filtration rate, m / day; $H_1$ - pressure of the filtered liquid at $x = 0$, m; $H_2$ - pressure of the filtering liquid at $x = L_f$, m; $L_f$ - distance between horizontal drains, m.

Pressure gradient $J$, the filtration rate of the APP will be the same at all points of the filtration area in the placer massif. If the open area of the filtration flow is taken as $F$, then the filtration flow rate will be

$$Q = K_f \cdot F \frac{H_1 - H_2}{L_f}.$$  (4)

If the shape of the placer polygon is rectangular, then

$$F = b \cdot T,$$  (5)

where $T$ - the thickness of the peat bed, m; $b$ is the width of the landfill (flow width), m.

Specific filtration flow rate is defined as

$$q = \frac{Q}{b}.$$  (6)

Substituting (4) in (6) we obtain

$$q = K_f \cdot T \frac{H_1 - H_2}{L_f}.$$  (7)

In the case of conformal mapping of the region of the reduced complex potential of one-dimensional steady-state filtration, which occurs in a permeable peat layer during filtration of an incompressible
activated reagent solution, the flow has a free surface in the form of an inclined plane with a slope equal to the slope of the raft \( i = \tan \alpha \). In this case, the piezometric slope is the slope of the free surface of the raft and is equal to the slope \( (i) \), and therefore the filtration rate at any point in the placer will be

\[
V = K_f \cdot i. \tag{8}
\]

Filtration flow rate of APP

\[
Q = F \cdot V = K_f \cdot F \cdot i, \tag{9}
\]

or taking into account the mathematical model obtained in laboratory experiments

\[
Q = 63.4 \cdot e^{-0.119C_a} \cdot F \cdot i. \tag{10}
\]

During filtration and drainage thawing, horizontal drainage takes place, i.e. the case of symmetric filtering. Therefore, when determining the area of the reduced complex filtration potential, we will take the plane of the horizontal drain as the plane of comparison of the pressures. In this case, the flow area of the filtration flow is rectangular, then

\[
F = b \cdot H. \tag{11}
\]

From the formula (10) the specific consumption will be

\[
q = 63.4 \cdot e^{-0.119C_a} \cdot i \cdot H. \tag{12}
\]

Hence, the distance between the ditches will be

\[
L_f = \frac{H \cdot K_f \cdot T}{q}. \tag{13}
\]

Taking into account the rheological properties of the filter fluid, the distance between horizontal drains can be determined by the formula

\[
L_f = \frac{H \cdot K_f \cdot T \cdot \nu_0}{q \cdot \nu \cdot \mu_{gr}}, \tag{14}
\]

where \( \nu \) is the viscosity of the activated reagent solution, mPa \( \cdot \) s; \( \nu_0 \) - viscosity of water, mPa \( \cdot \) s; \( \mu_{gr} \) - coefficient of gravitational fluid loss, unit fractions.

Obviously, when filtration in a peat bed formed from \( n \) parallel layers with thicknesses \( T_1, T_2, ..., T_n \) and filtration coefficients \( K_1, K_2, K_3, ..., K_n \), in each layer there is a one-dimensional steady-state filtration (the second variant of the calculation). Then, according to (7), in the \( m \)-th layer, the specific filtration flow rate is

\[
q_m = K_m \cdot T_m \cdot \frac{H_1 - H_2}{i}. \tag{15}
\]

When using boreholes, it will be correct to use the equations of axisymmetric one-dimensional filtration in cylindrical coordinates [3,7]:

\[
\frac{d}{dr} \left( r \frac{dh}{dr} \right) = 0. \tag{16}
\]

After integrating this equation, we obtain the pressure value

\[
H = \frac{Q}{2\pi T} \ln \frac{r}{r_0} + h_0. \tag{17}
\]
where $h_0$ is the head in the well itself, m; $r$ - cylindrical coordinates of motion of the activated reagent solution along the ($r$) axis.

The resulting expression is the equation of the pressure curve for filtration to the well. The equation of the pressure curve for the case of outflow from the well (absorbing well) has the form

$$h = -\frac{Q}{2\pi K_f T} \ln \frac{r}{r_0} + h_0.$$  \hspace{1cm} (18)

From the last equation, assuming that at a distance $R$ from the well $h = H$, we obtain the formula for the flow rate absorbed by the well

$$Q = \frac{2\pi K_f T (h_0 - H)}{\ln \frac{R}{r_0}}.$$  \hspace{1cm} (19)

As can be seen from formula (19), to determine the desired distance $R$ from the well, it is necessary to know the flow head, flow rate and rheology of the filtering APP

$$R = \frac{V_0}{v \mu_r e^{\frac{2\alpha K_f T}{\mu_r}}}. $$  \hspace{1cm} (20)

4. Conclusion

As a result of laboratory and industrial experiments, it was found that the treatment of peats with an activated reagent solution can increase the filtration rate by 2-4 times. The achieved effect made it possible to prepare artificial sushenitsy zones on peat with a clay content of up to 15%.

It has been found that when the area of the reduced complex potential of one-dimensional steady-state filtration, which occurs in a permeable layer of peat during filtration of an incompressible activated reagent solution, is displayed conformally, the flow has a free surface in the form of an inclined plane with a slope equal to the slope of the raft. In this case, the piezometric slope is the slope of the free surface of the raft.

When using boreholes for thawing peat, the calculation of the parameters of the technology for the preparation of artificial sushenitsy must be carried out according to the equations of axisymmetric one-dimensional filtration in cylindrical coordinates.

It is recommended to thaw peat with a thickness of up to 6 meters using the most economical filtration and drainage method. In the case of a greater thickness of peat (up to 8 m), they should be thawed using boreholes.

When preparing artificial sushenitsy at placer deposits, the main types of drainage workings are horizontal drains. If the depth of thawing is much greater than the distance between drains, the placement of the latter should be at least 3 meters with a depth of peat up to 6 meters.

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