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Terms of melting the permafrost when cementing of boreholes plugged with gas-liquid mixtures with hollow microspheres

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Abstract

In the paper, the theoretical investigations are presented to define heat conductivity of gas-liquid cement slurries and formed set cement, containing silica-alumina hollow microsphere. It has been established that increasing the content of the hollow microspheres and aeration of the cement slurry leads to heat conductivity reduction of the slurry and set cement.

Keywords: gas-liquid mixture of cement, hollow aluminosilicate microspheres, permafrost, permafrost, cementing, conditions of immelting, conductivity.

INTRODUCTION

Russia occupies a leading position in the production of diamonds in the world. The largest diamondiferous deposits of our country are concentrated in harsh climate and difficult geological conditions.

Currently, many diamond deposits development is carried out by underground method. When this problem occurs, which is characterized by flow in underground mine workings selfnomination groundwater. This issue is related to entering production brines, is solved by pumping of drainage water through wells in under or between permafrost layers.

Methodology for determination of the conditions of the melting of frozen rocks

Cementing works in permafrost conditions should be carried out subject to certain temperature conditions in the well, the violation of which leads to the formation of voids, the development of the annular flow of fluids and the loss of contact between the backfill material and rocks, that conclude ice.

The ice contained in permafrost, begins to melt at a positive temperature of the cement mixture ($t_{cm} > 0$ ° C). In this case, to prevent the thawing of the areas of distribution of permafrost (ADP), the temperature of the walls of the wells must not exceed the temperature of the occurrence of the phase transition. If this condition is achieved with the inequality proposed by B. B. Kudryashov [1]. For gas-liquid cement mixture (GLCM) containing hollow microspheres, in dimensionless variables is of the form:

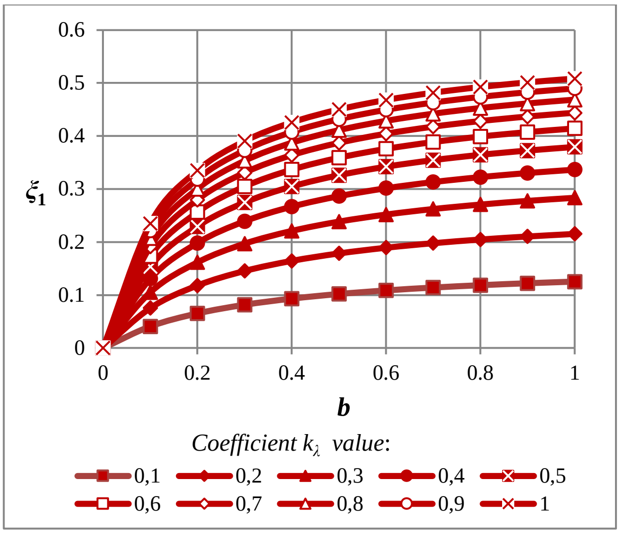
$$\theta_0 \le \theta$$

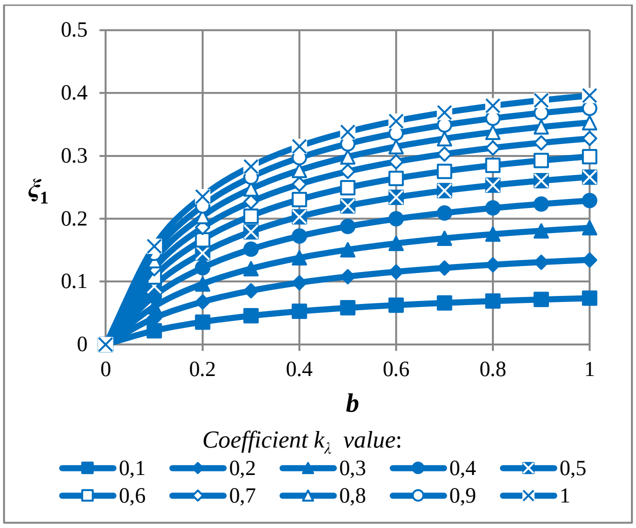
$$\text{при } \theta = \frac{1 - Q_{gl} \cdot \xi_1}{\xi_2}, \ \theta_0 = \frac{t^0_{gl} - T_r}{T_r},$$

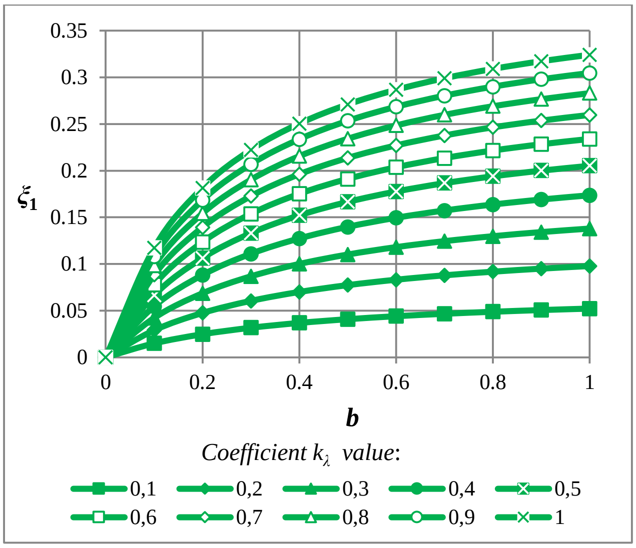
$$Q_{gl} = \frac{\omega \cdot Q^{\sum}_{gl}}{C_{gl}(-T_r)}, \ Q^{\sum}_{gl} = \frac{(1-\psi - r)\cdot Q_{cm} \cdot (1 - e^{-\alpha\tau})}{\rho_{gl}}, \tag{1}$$

$$\psi = \frac{\alpha}{\alpha + 1 + h \cdot \rho_{lm}/\rho_m + \rho_{lm}/(m \cdot \rho_c)}, r = \frac{t/\rho_m}{t/\rho_m + 1/\rho_c + m/\rho_{lm}(a+1)},$$

where T_r and t^0_{g1}, respectively, the initial temperature of frozen rocks and GLCM comprising hollow microspheres ° C; $Q^{\sum}_{gl}$ – total amount of heat released during the solidification of a unit mass of cement, kJ/m3; ω is the mass fraction of cement in solution; C_{gl} – specific heat GLCM with hollow microspheres, j/(kg·°C); ρ_{gl}, ρ_{lm}, ρ_c, ρ_m, respectively, the density GLCM, including hollow microspheres, liquid mixture, cement and hollow microspheres, kg/m3; *h* - dimensionless coefficient equal to the ratio of the weight of PAMS to water weight, G_m = (2-2,5 %)G_{water}; *t* is the dimensionless coefficient equal to the ratio of weight of microspheres to the weight of cement, of G_m = (1/15 %)G_c; α is the parameter, that characterize the intensity and rate of heat release (in the first approximation α = const and depends only on the initial temperature *GLSM* with hollow microspheres), hour-1; τ – time, h; and the degree of aeration of the solution; Q_{cm} – maximum dissipation of the backfill mixture, kJ/m3; ξ_1 and ξ_2 – the maximum value functions, which are found in accordance with [1] and is shown in Figure 1.







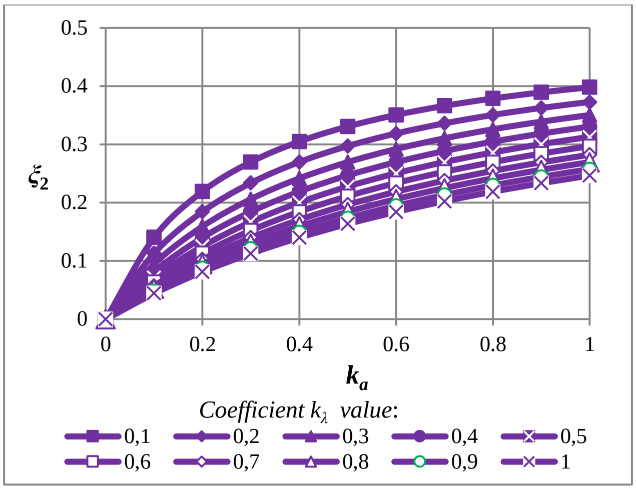


Figure 1 (a,b,c,d): Dependence of the functions ξ_1 and ξ_2 parameters k_λ, k_a and b a) k_a = 0,1; b) k_a = 0,2; c) k_a = 0,3

Functions ξ_1 and ξ_2 depend on parameters k_λ, k_a and b that are tailored thermophysical properties GLCM hollow microspheres [2] are calculated by the following formulas:

$$k_\lambda = \frac{\lambda_{\text{gl}}}{\lambda_{\text{r}}},\ k_a = \frac{a_{\text{gl}}}{a_{\text{r}}},\ b = \frac{a_{\text{gl}} R_{\text{c}}^2}{a_{\text{r}}} = k_a R_{\text{c}}^2, \tag{2}$$

where λ_{gl}, λ_r – respectively, coefficients of thermal conductivity GLCM with hollow microspheres and frozen rocks, W/(m·°C); a_{gl}, a_r – respectively, coefficients of thermal conductivity GLCM with hollow microspheres and frozen rocks, m^2/s; R_w – radius of the well, m.

After determining the parameters of k_λ, k_a and b that depend on the thermophysical properties of backfill mixes, and frozen rocks, by the relationships in figure 1 can be set of function values ξ_1 and ξ_2.

Heat capacity, thermal conductivity, thermal diffusivity and volumetric weight of the frozen soils $\gamma_{\text{vol}}^{\text{r}}$ depend on the content of ice in them and, correspondingly, calculated using the following formulas [3]:

$$C_{\text{п}} = \frac{C_{\text{sk}} + C_{\text{i}}\eta}{1+\eta},\ \lambda_{\text{r}} = (1-\eta)\lambda_{\text{sk}} + \eta\lambda_{\text{i}},$$
$$a_{\text{r}} = \frac{\lambda_{\text{r}}}{C_{\text{r}}\gamma_{\text{vol}}^{\text{r}}},\ \gamma_{\text{vol}}^{\text{r}} = \frac{0{,}9\gamma_{\text{sk}}(1+\eta)}{0{,}9+\eta\gamma_{\text{sk}}}, \tag{3}$$

where C_{sk} is the specific heat of the mineral skeleton of rocks, J/(kg·°C); C_i – specific heat of ice, J/(kg·C); η is the volumetric ice content of the soil due to ice inclusions in fractions of a unit; λ_{sk} – coefficient of thermal conductivity of mineral skeleton of rocks, W/(m·°C); λ_i – coefficient of thermal conductivity of ice, W/(m·°C); the γ_{sk} is the specific weight of the mineral skeleton of rocks, g/cm^3.

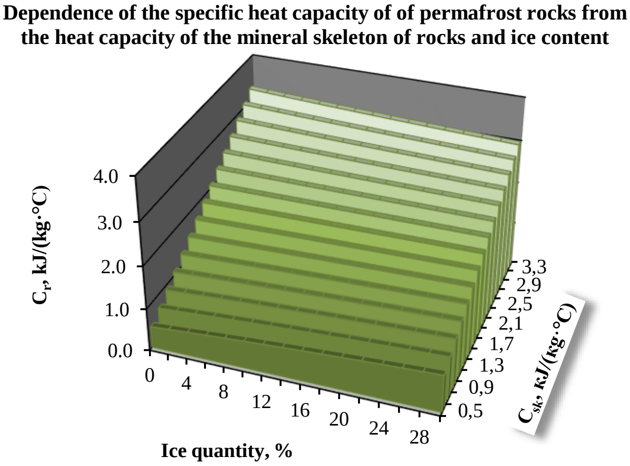
Example of using of this Methods:

Within easy reach of the diamondiferous deposits of «Udachnaya» pipe is the range of the pumping drainage water Kiyengsi (Table 1). Here water holding aquifers are composed of limestones and marls [4]. For these conditions the calculations are made for determination of the initial temperature GLCM with hollow microspheres, which will not come thawing of frozen rocks.

Table 1. Characteristics of permafrost in various forms of relief, dedicated to Kiengsciy landfill [5]

The situation in the terrain	The main temperature range, °C	Indicators podmerzaniya aquifer	
		Abs. mark roof, m	The water mineralization, g/dm3
River valley	–2,2…–4,0	+145…+173	100–110
The watershed	–1,3…–2,6	+156…+190	40–80

The dependence of the heat capacity and thermal conductivity of permafrost rocks from the thermophysical properties of the mineral skeleton of rocks and the percentage of ice is presented in figure 2.



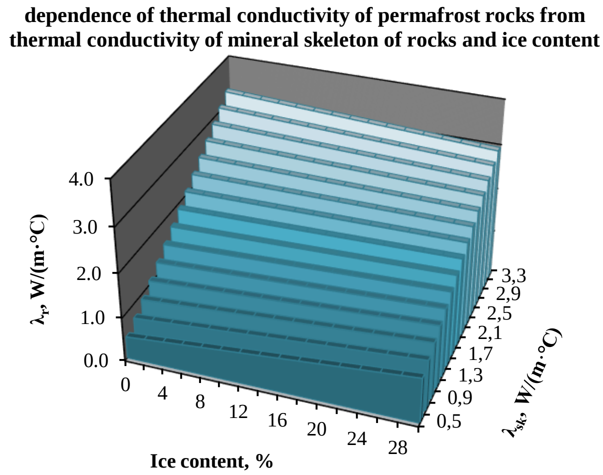
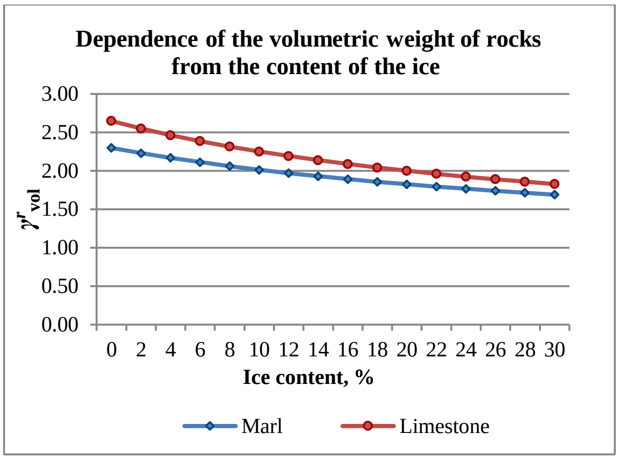


Figure 2 (a,b). Dependence of the thermophysical characteristics of the permafrost rocks from the properties of the mineral skeleton of rocks and ice quantity.

The heat capacity and the thermal conductivity of the permafrost rocks increased with the growth of the ice in the case when the same thermal and physical characteristics of the mineral skeleton of frozen rocks have values not exceeding similar values for the ice.

Figure 3 shows the dependence of the values of bulk density and thermal diffusivity of rocks from ice content.



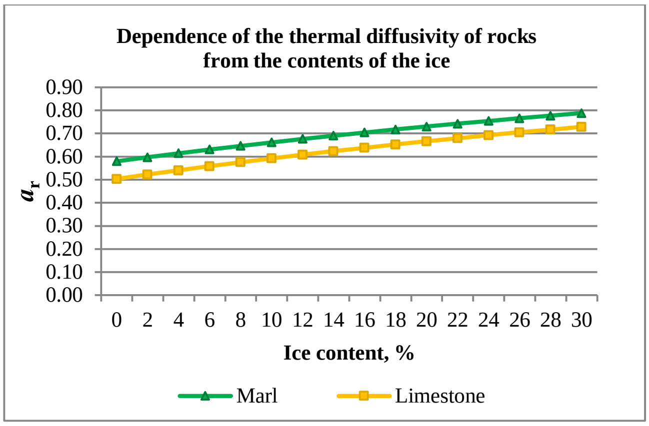
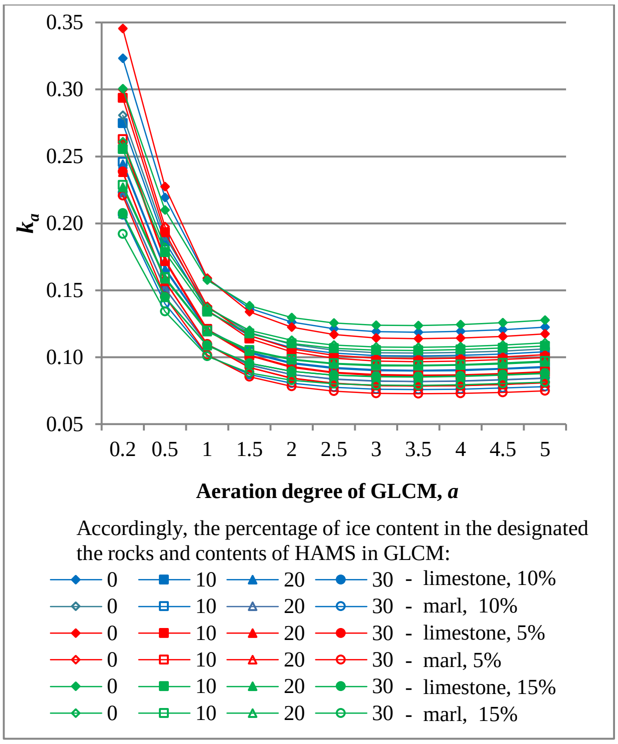


Figure 3 (a,b). Based on the bulk density and thermal diffusivity of rocks from the content of the ice.

For the adopted characteristics of rocks on the ground Kiengskiy determined parameters k_λ and k_a, the results of the calculations are presented in figure 4.

Shown in figure 4 the dependencies determined for the rocks composing the bulk thickness of frozen rocks on Kievskiy site. The mineral skeleton of permafrost regions is composed of limestones and marls. The ice content of the rocks reaches 30 %. The calculations were made values thermal characteristics GLCM with the degree of aeration of 0.2 to 5 and a content of hollow microspheres of 5 to 15 % (by weight of the solid phase of the mixture).



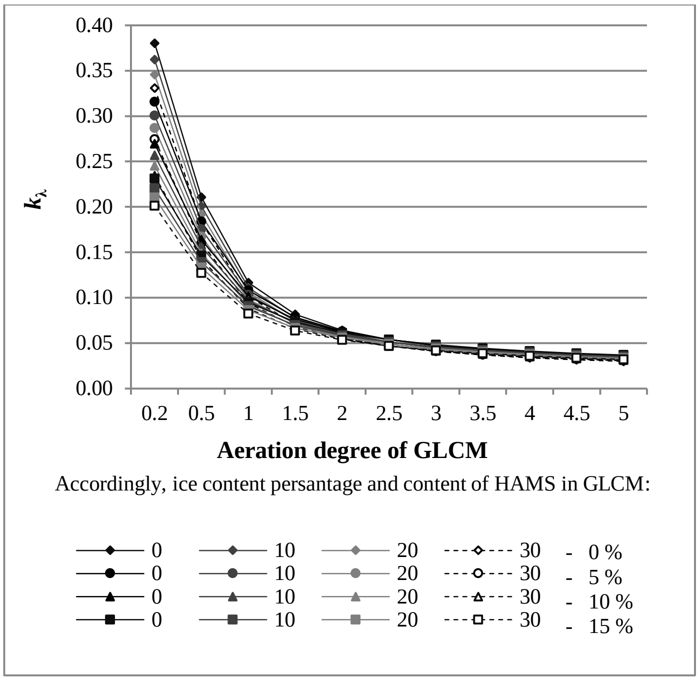


Figure 4 (a,b). Dependences of parameters k_λ, k_a is the degree of aeration of contents of the microspheres, the thermo-physical properties of rocks and ice content.

According to the method, which was determined and described earlier in this paper, determined the conditions under which the frozen rocks will not start melting under the influence of heat coming from GLCM with HAMS in the process of plugging the annulus and the formation of cement stone. The results of the calculations are presented in Fig. 5 and Fig. 6.

The result of numerical analysis we estimated the impact of aeration rate (0.2 to 1) cement blend, water relations (0,4), the content of HAMS (5-15 weight parts), the borehole diameter (and 0.172 m) of the composition and properties of frozen rocks on the maximum allowable initial temperature GLCM with the inclusion of hollow microspheres.

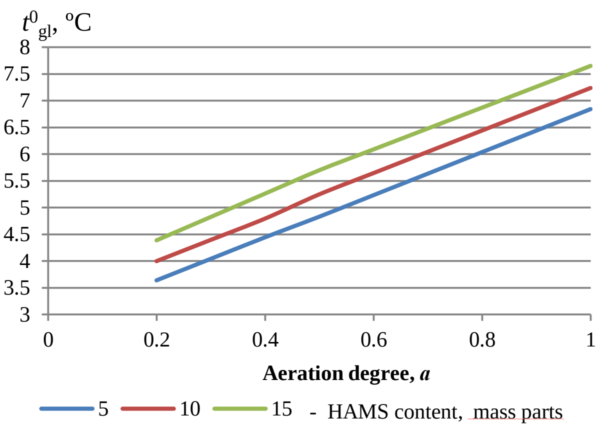


Figure 5. The dependence of the limiting starting temperature GLCM with HASM, the degree of aeration GETS and content of

ASPM for limestone with a temperature of -1°C and a content of ice 10 %.

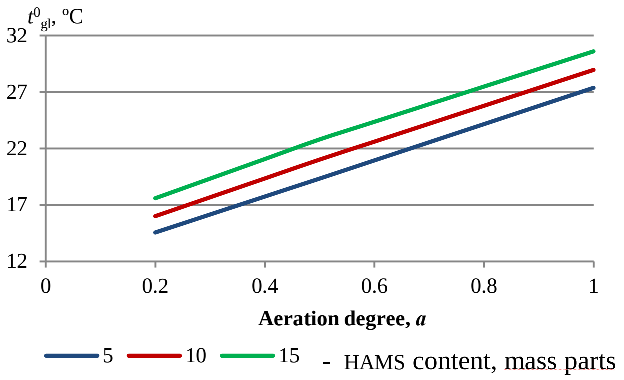


Figure 6. The dependence of the limiting starting temperature GLCM with HASM, the degree of aeration GLCM and content of HASM for limestone with a temperature of -4°C and ice content of 10 %.

Increasing the gas component grouting mixture, low temperature MMP and increased content in the rock, ice provides the possibility for well injection GLCM with HAMS with higher temperature, which will not affect the thawing of the walls of the well.

In our country, for conditions typical of the far North and North-Eastern part of well cementing, it is recommended to use a cement slurry with an initial temperature of from 10 to 20°C regardless of the temperature of the components contained in cement mixtures, and ambient temperature [6, 7].

CONCLUSION

According to the above method increasing the gas component grouting mixture, low temperature permafrost rocks and increased content in the rock, ice provides the possibility for well injection GLCM with HAMS with higher temperature, which will not affect the thawing of the walls of the well.

To prevent thawing the frozen soils is possible by regulating gas draw and water relations of grouting mixture, and also pre-cooling of its components [1, 7, 8]. In addition, the indicated problem may be solved by included in GLCM hollow microspheres.

In the production of cement works in the permafrost zone, we must perform a preliminary forecast of the composition and properties GLCM with HAMS in the degree of aeration, the content of hollow microspheres and water relation with the composition overlap of frozen rocks, content of ice and their temperature.

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