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INFLUENCE OF GAS WELL THERMAL INSULATION PARAMETERS ON THAWING INTENSITY OF PERMAFROST AND INTRAPERMAFROST GAS HYDRATES

Z.A. Vasil'eva, V.S. Yakushev

Gubkin Russian State University of Oil and Gas, Department of Gas Production, 65, Lenina ave., Moscow, 119991, Russia; zoyavac@gmail.com

Based on the model of thermal interaction between a production well and the surrounding permafrost rock massif containing relic metastable hydrates, we estimated the intensity of permafrost thawing and associated intrapermafrost gas liberation, considering the parameters of thermal insulation of wells. For the first time, the inverse problem is solved where thermal insulation parameters of a well are defined at a given thaw radius through a given period of its operation. The dependence of necessary thermal conductivity of the flow string heat insulation on the thermal conductivity of cement at a given thaw radius has been obtained.

Permafrost, metastable gas hydrates, gas emission, phase transition boundary, radius of thermal influence of wells

INTRODUCTION

Gas fields development in northern West Siberia is accompanied by numerous challenges caused by thermal effect from producing wells on the surrounding permafrost. In localities where permafrost interval is represented by dispersive ice-rich soils, liberation of combustible gases often takes place near wellheads. As such, gas emissions are associated with the thawing of intrapermafrost gas hydrates and infiltration of the released gas into the borehole environment [*Yakushev, 2009*]. The initial assessment of thawing rate around the thermally uninsulated producing wells in the permafrost conditions of the Yamal Peninsula showed that during the first year, their thawing radius can reach 6 m and the volume of gas liberated from permafrost – up to $36 \cdot 10^3$ m^3 [*Vasil'eva et al., 2016*]. Given that wells in the permafrost region require thermal protection to reduce the rate of permafrost thaw, it therefore appears practical to seriously consider methods of passive thermal insulation of boreholes.

In case of the clustered wells location (when drilled from one well pad) and their long-term operations, the implications are that the thawing halos around individual wells can merge if the distance between the latter is less than two thaw radii.

To that end, various methods of increasing the thermal resistance at the "wellbore-permafrost" contact are applicable, to reduce the thermal impact of the production well on the surrounding permafrost.

Both the well design solutions and distances between them are based on modeling the permafrost soil thawing process around the thermally insulated and uninsulated wells of various designs. The following thermal insulation solutions for wells are known as basic: vacuum insulated tubing (VIT), thermo-cases (thermal insulation of surface casing), heat-insulating paints, cements with reduced thermal conductivity (for example, hollow ceramic microspheres).

It is therefore essential to estimate the minimum size of the zone of a well pad placement, establishing thereby a distance between them, at which their thermal interplay is reported. In [*Gorelik et al., 2008*] developed a method for numerical solution of the three-dimensional Stefan problem describing the permafrost thaw dynamics in the zone of influence of two producing wells.

It is shown that over a lengthy time which takes from the moment of taliks merging, the non-steady and steady temperature fields as well as the thawing region geometry near the wells tend to differ substantially. The existing analytical methods of thermal calculations allow to evaluate the thermal field of rock mass assuming fairly constant temperatures either in oil/gas flow in the well and on the wall of the hole (stationary problem) [*STO Gazprom..., 2008; Khrustalev and Gunar, 2015*], or constant temperature of fluid alone in the well (non-stationary problem) [*Korotaev et al., 1976; Istomin et al., 1981*].

In this paper, we consider the borehole and rock mass as a single heat exchange system, and both the fluid temperature in the borehole and rock temperature are variable, whereas the heat flux at the borehole wall is assumed to be constant.

PROBLEM FORMULATION

The intensity of permafrost thawing and affiliated gas liberation were estimated using a model of thermal interaction between a producing well (which has a production casing with inner radius r_0 and a cement sheath with an outer radius r_c) and the permafrost interval containing relic, metastable hydrates. This option for casing without thermal insulation was evaluated earlier in [*Vasil'eva et al., 2016*].

The rocks surrounding a borehole have porosity m and initial ice saturations of pore space s_{i0}, hydrate

s_{h0} and water s_{w0}. During the well operations gas moves through it at a temperature T_g = 303 K (+30 °C), promoting thereby the growth of thawing halo around the well ($r_c \leqslant r < R_*(t)$), conjugated with permafrost zone ($R_*(t) < r < \infty$). Here $R_*(t)$ is a moving boundary of phase transition; t is time. The heat flow in a vertical direction can be neglected, in this case.

In the thawed zone of coexisting gas and water, the energy conservation law is written as

$$\text{at } r_c \le r < R_*(t) \quad \frac{\partial T_1}{\partial t} = a_1 \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_1}{\partial r}\right), \quad a_1 = \frac{\lambda_1}{(c\rho)_1}. \quad (1)$$

In the frozen zone of coexisting gas and water, hydrate and ice, the energy conservation law is applicable

$$\text{at } r_c \le r < R_*(t) \quad \frac{\partial T_2}{\partial t} = a_2 \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_2}{\partial r}\right), \quad a_2 = \frac{\lambda_2}{(c\rho)_2}, \quad (2)$$

where a_j is temperature conductivity; $(c\rho)_j$ is specific heat per unit volume; λ_j is thermal conductivity; T_j is temperature of j-th zone (j = 1, 2); ρ is density; c is specific heat. Index 1 is accounted for the thawed zone, index 2 – for the frozen zone.

Initial and boundary conditions are taken as

$$\text{at } t = 0, \quad r > r_c \quad T = T_0, \quad s_i = s_{i0}, \quad s_h = s_{h0}; \quad (3)$$

$$\text{at } t > 0, \quad r = \infty \quad T_2(r) = T_0; \quad (4)$$

while on the moving boundary of phase transition they are written as

at $r = R_*(t)$

$$\left(\lambda_2 \frac{\partial T}{\partial r}\right)^+ - \left(\lambda_1 \frac{\partial T}{\partial r}\right)^- = m\left(\rho_h q_h s_h^+ + \rho_i q_i s_i^+\right)\frac{dR_*}{dt}; \quad (5)$$

$$T_1(r)^+ = T_2(r)^- = T_*. \quad (6)$$

Here T_* is temperature of permafrost soil thawing; T_0 is *in situ* permafrost temperature; q_h, q_i is latent to heat of the hydrate-to-ice transition. Indices w, h, g, i, s correspond to water, hydrate, gas, ice and solid matrix, respectively. Symbol "+" denotes the value to the right of the boundary (right-hand limit), and symbol "–" is the value to the cleft of the boundary (left-hand limit).

Boundary condition is a matching condition for temperature-fields of gas in the hole and of rocks as gas moves through it, which is written as

$$\text{at} \quad r = r_c,\ t > 0 \quad k_D\left(T_g - T_c\right) = -\lambda_1 \frac{\partial T}{\partial r} = \frac{W}{2\pi h r_c}, \quad (7)$$

where T_c is temperature at the cement sheath surface averaged for the investigated interval length of the hole; W is heat flux through the outer surface of the cement sheath.

The heat transfer coefficient for thermally insulated wells is largely influenced by the well design, as well as by applications of active and passive thermal insulation. These include: the air gap between the production string and intermediate column (protection casing string), and the insulation ring encircling the vacuum insulated tubing (VIT).

Heat-transfer coefficient for thermally insulated wells after [*Khrustalev and Gunar, 2015*], is written as

$$k_D = \left(\frac{1}{\alpha} + \frac{r_{ins}}{\lambda_{ins}}\ln\left(\frac{r_{ins}}{r_0}\right) + \frac{r_p}{\lambda_{ef}}\ln\left(\frac{r_p}{r_{ins}}\right) + \frac{r_c}{\lambda_c}\ln\left(\frac{r_c}{r_p}\right)\right)^{-1}.$$

The research conducted by [*Isachenko et al., 1969*] provides the following formula for calculating the heat transfer coefficient:

$$k_D = \left[r_c\left(\frac{1}{\lambda_{ins}}\ln\left(\frac{r_{ins}}{r_0}\right) + \frac{1}{\lambda_{ef}}\ln\left(\frac{r_p}{r_{ins}}\right) + \frac{1}{\lambda_c}\ln\left(\frac{r_c}{r_p}\right)\right)\right]^{-1},$$

where r_{ins}, r_p are radii of the encircling insulating medium and of production string; λ_{ins}, λ_{ef}, λ_c are coefficients of thermal conductivity for: thermal insulation (λ_{ins}), effective thermal conductivity of the air, once convective heat transfer is replaced by conductive (λ_{ef}), and of cement sheath (λ_c).

Given that the literature does not provide a principle, which may generate a unified concept of the heat transfer coefficient, the necessity arises as to derive *the heat transfer coefficient for thermally insulated wells.*

The steady-state heat conduction equations for thermal insulation $(r_0 < r < r_{ins})$, effective thermal conductivity of air $(r_{ins} < r < r_p)$ (when convective heat transfer is replaced by conductive) and cement sheath $(r_p < r < r_c)$ are written as

$$\text{at } r_0 < r < r_{ins} \qquad \frac{d^2 T_{ins}}{dt^2} + \frac{1}{r}\frac{dT_{ins}}{dr} = 0; \quad (8)$$

$$\text{at } r_{ins} < r < r_p \qquad \frac{d^2 T_{ef}}{dt^2} + \frac{1}{r}\frac{dT_{ef}}{dr} = 0; \quad (9)$$

$$\text{at } r_p < r < r_c \qquad \frac{d^2 T_c}{dt^2} + \frac{1}{r}\frac{dT_c}{dr} = 0 \quad (10)$$

with the boundary conditions of:

heat loss on the wall of vacuum-insulated tubing (VIT heat loss)

$$\text{at } r = r_0 \qquad \frac{dT_{ins}}{dr} = -\frac{\alpha}{\lambda_{ins}}\left(T_g - T_{ins}\left(r_0\right)\right), \quad (11)$$

continuity of heat fluxes and temperature:

$$\text{at } r = r_{ins} \qquad \lambda_{ins}\frac{\partial T_{ins}}{\partial r} = \lambda_{ef}\frac{\partial T_{ef}}{\partial r}, \quad T_{ins} = T_{ef}; \quad (12)$$

$$\text{at } r = r_p \qquad \lambda_p\frac{\partial T_p}{\partial r} = \lambda_{ef}\frac{\partial T_{ef}}{\partial r}, \quad T_p = T_{ef}; \quad (13)$$

$$\text{at } r = r_c \qquad \lambda_c\frac{\partial T_p}{\partial r} = \lambda_1\frac{\partial T_1}{\partial r}, \quad T_p = T_1. \quad (14)$$

Solving task (8)–(14) results in the condition at the cement sheath wall

$$\left(T_1-T_g\right)\left[\frac{r_c}{r_0\alpha}+\frac{r_c}{\lambda_{ins}}\ln\left(r_{ins}/r_0\right)+\frac{r_c}{\lambda_{ef}}\ln\left(r_p/r_{ins}\right)+\right.$$
$$\left.+\frac{r_c}{\lambda_c}\ln\left(r_c/r_p\right)\right]^{-1}=\lambda_1\frac{dT_1}{dr}.$$

Hence, the expression for heat transfer coefficient for thermally insulated wells is calculated by

$$k_{D1}=\left[\frac{r_c}{r_0\alpha}+\frac{r_c}{\lambda_{ins}}\ln\left(r_{ins}/r_0\right)+\frac{r_c}{\lambda_{ef}}\ln\left(r_p/r_{ins}\right)+\right.$$
$$\left.+\frac{r_c}{\lambda_c}\ln\left(r_c/r_p\right)\right]^{-1}, \tag{15}$$

for an uninsulated well (cement alone)

$$k_{D2}=\left[\frac{r_c}{r_0\alpha}+\frac{r_c}{\lambda_c}\ln\left(r_c/r_0\right)\right]^{-1}, \tag{16}$$

for a well with VIT insulation

$$k_D=\left[\frac{r_c}{r_0\alpha}+\frac{r_c}{\lambda_{ins}}\ln\left(r_{ins}/r_0\right)+\frac{r_c}{\lambda_c}\ln\left(r_c/r_{ins}\right)\right]^{-1}. \tag{17}$$

Given that initial and boundary functions of temperature, hydrate saturation and ice content (T_0, W, s_{h0}, s_{i0}) are constant values, the problem (1)–(7) at $r_c\to 0$ is *self-similar* whose solution is given by $T=T(\xi)$, $R_*=\delta t^{1/2}$, $\xi=rt^{-1/2}$. In the theory of unsteady seepage of liquids and gases [*Barenblatt et al., 1972; Basniev et al., 2005*], the main problem – *nonstationary gas flow to a well* – requires a self-similar solution (a gas well is thought of as a point (flowing pressure) or source). The theory of hydrodynamic studies of wells is based on the self-similar solution at $r=r_c$, inasmuch as the pressure and temperature measurements can be taken only at the bottomhole [*Erlager, 2007; Instructions..., 2010*]. Geophysical investigations of wells are also based on the self-similar solution of the *instantaneous point-source problem* [*Barenblatt, 1978*]. These investigations are corroborated by the many years of practical applications. Therefore, despite the fact that the actual well radius is a finite value, the self-similar solution is to be considered in this case, which is an asymptotic solution to the original problem.

The problem formulation in self-similar variables is written as:

thawed zone $$\frac{d^2T_1}{d\xi^2}+\frac{dT_1}{d\xi}\left(\frac{1}{\xi}+\frac{\xi}{2a_1}\right)=0, \tag{18}$$

frozen zone $$\frac{d^2T_2}{d\xi^2}+\frac{dT_2}{d\xi}\left(\frac{1}{\xi}+\frac{\xi}{2a_2}\right)=0\;; \tag{19}$$

boundary conditions are given in

at $\xi\to 0$ $$\left(\xi\frac{dT}{d\xi}\right)_{\xi=0}=-\frac{W}{2\pi h\lambda_1}, \tag{20}$$

at $\xi\to\infty$ $$T=T_0, \tag{21}$$

at $\xi=\delta$ $$T=T_*,$$
$$\lambda_2\left(\frac{dT_2}{d\xi}\right)^+-\lambda_1\left(\frac{dT_1}{d\xi}\right)^-=m\left(\rho_h q_h \nu^+ +\rho_i q_i s_i^+\right)\delta/2. \tag{22}$$

Self-similar solution of task (18)–(22) is discussed in detail in [*Vasil'eva et al., 2016*].

Condition at the phase boundary (5) accounting for (17) takes the form

$$4\lambda_2\frac{T_0-T_*}{Ei\left(-\delta^2/4a_2\right)}\exp\left(-\frac{\delta^2}{4a_2}\right)+$$
$$+\left(\frac{2\left(T_g-T_c\right)\exp\left(-\frac{\delta^2}{4a_1}\right)}{\left(1/r_0\alpha\right)+\left(1/\lambda_{ins}\right)\ln\left(r_{ins}/r_0\right)+\left(1/\lambda_c\right)\ln\left(r_c/r_{ins}\right)}\right)=$$
$$=m\left(\rho_h q_h s_h^+ +\rho_i q_i s_i^+\right)\delta^2\,. \tag{23}$$

A transcendental equation (23) is used for determining δ – the moving phase boundary parameter $R_*=\delta t^{1/2}$.

The heat-transfer coefficient can be derived from the transcendental equation (23)

$$k_D=\frac{m\left(\rho_h q_h s_h^+ +\rho_i q_i s_i^+\right)\delta^2}{2r_c\left(T_g-T_c\right)\exp\left(-\frac{\delta^2}{4a_1}\right)}-$$
$$-2\lambda_2\frac{T_0-T_*}{Ei\left(-\delta^2/4a_2\right)r_c\left(T_g-T_c\right)}\exp\left(\frac{\delta^2}{4a_1}-\frac{\delta^2}{4a_2}\right). \tag{24}$$

Analysis of the influence of gas wells thermal insulation parameters on the intensity of permafrost and intrapermafrost gas hydrates thawing

Figures 1 and 2 show the results of calculations performed with the MATHCAD software complex using mean parameter values in the upper 100 meters of the permafrost zone in the southern part of Bovanenkovo gas-condensate field (GKF) [*Chuvilin, 2007*] and in the presence of relic hydrates (15 % of the pore volume) [*Yakushev, 2009*].

Initial conditions: T_0 = 268 K, T_g = 303 K, m = 0.45, s_{i0} = 0.76, s_{h0} = 0.15. Ice and hydrate parameters: ρ_i = 900 kg/m^3, ρ_h = 900 kg/m^3, ρ_{0g} = = 116 kg/m^3, T_* = 271 K, q_h = 43.7·10^4 J/kg, q_i = = 33·10^4 J/kg. Borehole parameters: r_0 = 0.072 m, r_c = = 0.213 m, r_{ins} = 0.084 m, r_p = 0.122 m. Thermophysical properties of the thawed zone: $(c\rho)_1 = 267 \cdot 10^4$ J/K, λ_1 = 3.32 W/(m·K) and frozen zone: $(c\rho)_2$ = = $186 \cdot 10^4$ J/K, λ_2 = 3.87 W/(m·K).

Fig. 1 shows the thawing radius growth dynamics around a natural gas well at a flow temperature +30 °C for three variants: "without insulation" – with thermal conductivity of cement λ_c = 1.28 W/(m·K); "insulation 1" – with passive thermal insulation (e.g., from foamed polystyrene) around the vacuum insulated tubing with thermal conductivity λ_{ins} = = 0.04 W/(m·°C) , which is followed by the cement sheath with standard cement λ_c = 1.28 W/(m·°C); "insulation 2" – with the identical insulation encircling the VIT, although with low thermal conductivity cement λ_c = 0.4 W/(m·°C).

During the first year of the gas well operations, the radial distance of thaw around a well without thermal insulation reached 3.8 m, and equaled 20.6 m over the 30-year period of the well operations, i.e., given the distance between wells within one cluster is 40 m, the areas of thawed permafrost around them tend to overlap with each other.

At this, due to decomposition of intrapermafrost gas hydrates during the first year of thermally insulated gas well operations, ca. $50 \cdot 10^3$ m^3 of free gas is formed under normal conditions, which will total to ca. $1500 \cdot 10^3$ m^3 over the entire 30-year life of the producing well. The volume of gas liberated from the hydrates was calculated according to the formula in [*Vasil'eva et al., 2016*]

$$V_g = \pi R_*^2 H m \rho_{0g} s_{h0} \cdot 22.4/16.$$

Given the complicated permafrost conditions of the Yamal Peninsula and that the technologies intended for the gas and condensate fields development heavily exploit production well clusters, each is planned to include from 6 to 10 wells, it can be assumed that in case of thermally uninsulated wells, in 30 years, the thawing permafrost will liberate up to 15 million cubic meters of gas into the atmosphere and into permeable permafrost interlayers from a single well pad. The volume of released gas being that huge, it provides additional challenges for servicing gas wells and may lead to contingency situation at the wellheads, as was already reported from Bovanenkovo gas condensate field [*Chuvilin, 2007; Yakushev, 2009*].

Alternatively, application of passive thermal insulation to the production units within the permafrost interval can significantly reduce both the thawing radius and the volume of the gas liberated from the intrapermafrost gas-bearing formations. As is seen in Fig. 1, the thawing radii around insulated VIT differ only slightly. During the first year of gas well operation, the thawing radius with Thermal Insulation-1 reached 0.8 m, while with the use of Thermal Insulation-2 it did not exceed 0.6 m both growing to be 4.4 and 3.2 m, respectively, over the 30-year operation life of the well, i.e. the thawing radii areas do not overlap within one well cluster if the spacing between the wells is more than 10 m.

At this, the hydrate decomposition proceeded to a depth of H = 100 m during the first year of gas well operation using Insulation-1 and 2, yielded not more than $2.2 \cdot 10^3$ and $1.2 \cdot 10^3$ m^3 of gas formed under normal conditions, and ca. $67 \cdot 10^3$ and $36.5 \cdot 10^3$ m^3 over the 30-year life of the well, which indicates that the use of effective thermal insulation significantly reduces (by 20–40 times) the volumes of combustible gas liberated from the permafrost during the operation life of a well. At a very low thermal conductivity of VIT insulation λ_{ins} = 0.006 W/(m·°C) (e.g., with the use of super-thin basalt fiber (STBF) cylindrical blocks), the thawing radii constitute only fractions of a millimeter (Fig. 2).

During the first year of the well operation with the use of high thermal conductivity cement λ_c = 1.4 W/(m·°C) (Thermal Insulation-3), the thawing radius measured $4 \cdot 10^{-5}$ m; while with low thermal conductivity cement λ_c = 0.8 W/(m·°C) with Ther-

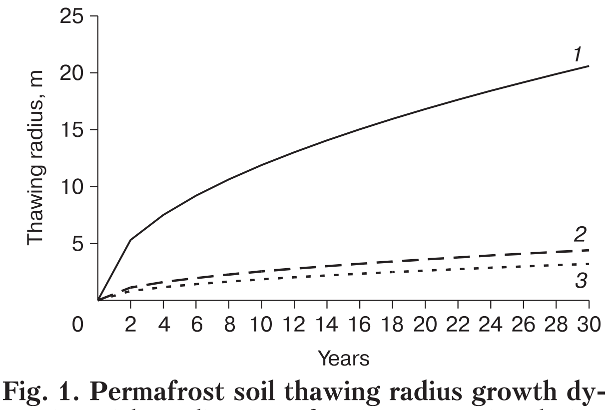

Fig. 1. Permafrost soil thawing radius growth dynamics with application of various types insulation of a well.

1 – uninsulated; *2* – Insulation-1; *3* – Insulation-2.

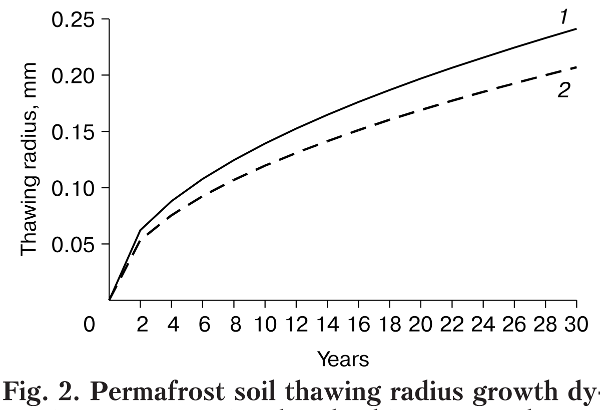

Fig. 2. Permafrost soil thawing radius growth dynamics at vacuum insulated tubing (VIT) thermal conductivity λ_{ins} = 0.006 W/(m·K).

1 – Insulation-3; *2* – Insulation-4.

mal Insulation-4 the thawing radius was $3.8 \cdot 10^{-5}$ m, and over the 30-year life of the well the radii measured $2.4 \cdot 10^{-4}$ and $2 \cdot 10^{-4}$ m, respectively.

With the energy dissipation taken into account, it can be assumed that VIT thermal insulation with such a low thermal conductivity is capable to bring down the rate of or even preclude permafrost thawing around the well and arrest affiliated gas liberation driven by hydrate decomposition.

Solution of the inverse problem of thermal interaction between the producing well and permafrost strata with trapped relic metastable hydrates

Analytical expressions (15), (19) for calculating heat transfer coefficient allow to solve the *inverse problem* stating that it is possible to determine the thermal insulation parameters of the well for a given thawing radius over a given period of well operation.

The moving phase boundary parameter δ is calculated from the thawing radius $r(t)$ over t years:

$$\delta = r(t) \Big/ \left(60\sqrt{24}\sqrt{365t}\right).$$

For example, the thawing radius formed during the 30-year operation life is expected to be 4.4 m, then $\delta = 1.4 \cdot 10^{-4}$ m. Using formula (24) we calculate heat-transfer coefficient $k_D = 0.75$. For thermal insulation parameters from (15) we obtain

$$\lambda_{ins} = \frac{\ln\left(r_{ins}/r_0\right)}{\left(k_D r_c\right)^{-1} - \left(r_0 \alpha\right)^{-1} - \left(1/\lambda_c\right)\ln\left(r_c/r_{ins}\right)}. \qquad (25)$$

With the known values $r_0 = 0.084$ m, $r_c = 0.213$ m, $r_{ins} = 0.09$ from formula (25) we derive the dependence between the thermal conductivity of flow string insulation and cement thermal conductivity (Fig. 3).

It can be deduced from Fig. 3 that with VIT thermal conductivity $\lambda_{ins} < 0.04$ W/(m·°C) the thawing radius is almost independent of cement thermal conductivity.

The VIT thermal insulation with thermal conductivity $\lambda_{ins} = 0.04$ W/(m·°C) (for example, foamed

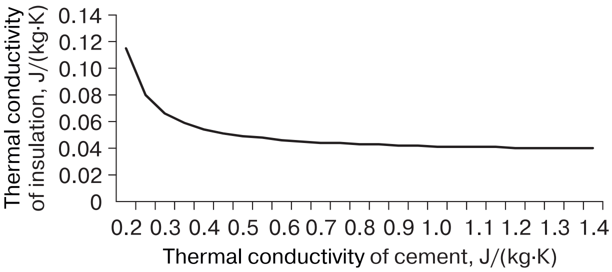

Fig. 3. Dependence of thermal conductivity of the flow string insulation on thermal conductivity of cement at heat-transfer coefficient $k_d = 0.75$ W/(m^2·K) and permafrost soil thawing radius 4.4 m in 30-years time period.

polystyrene) will thus allow application of high thermal conductivity cement, specifically, the one with rapid strength gain (for example arctic gypsum-based systems). Traditional cement mortars fasten without gaining strength. Gas evolved during the hydrate dissociation and permeating through the cement slurry, reduces its quality. Whilst a rapid strength gain will preclude gas penetration into the cement slurry.

CONCLUSIONS

The calculations have thus convincingly shown that the use of advanced effective thermal insulation materials with reduced thermal conductivity can either significantly reduce or completely arrest permafrost thawing and the affiliated liberation of intrapermafrost gas in gas wells in northern West Siberia.

In case of operation of thermally uninsulated wells, not only the risk of merging the thawing radii of wells in one cluster is high, but also that of significant emissions of gas trapped in permafrost, triggered by decomposing therethrough relic hydrates.

During the first year of operation of a thermally uninsulated well under the unparalleled permafrost conditions of the Yamal Peninsula, the thawing radius forming around producing wells is expected to measure 3.8 m, and the release of gas from the intrapermafrost hydrates – up to $50 \cdot 10^3$ m^3 within the depth interval of first 100 meters. Besides, it is usually aggravated by infiltration of the released gas into shallow permafrost layers, contributing thereby into gas pollution of the area under development.

The use of low thermal conductivity materials for VIT insulation, for example super-thin basalt fibers ($\lambda_{ins} = 0.006$ W/(m·°C)), can reduce the rate the thawing radius propagation to fractions of millimeters per year. Additionally, the gas pollution hazard within the production area tends to be appreciably reduced.

For the first time, the inverse problem is solved: the well thermal insulation parameters can be estimated for a given thawing radius, within a given period of well operation life. The dependence of the flow string insulation thermal conductivity on the thermal conductivity of cement is obtained at a given thawing radius, which allows to determine thermal conductivity of the VIT insulation, when thawing radius is practically independent of the thermal conductivity of cement. Then high thermal conductivity cement can be used, specifically, the type with a rapid strength gain capable of ensuring better adhesion of cement sheath to the surrounding rock.

Analytical solution of the inverse problem allows to determine the required thermal insulation parameters ruling out the thermal interplay of wells at a given geometry of the well pad placement, already at the gas fields design and construction stage in the permafrost regions.

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