Computer simulation of construction and operation of oil and gas fields of northern oil and gas fields with cloud technologies

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Abstract

In this work on the base of new mathematical model a software complex is developed for simulation and prediction of thermal processes in permafrost with presence of various engineering structures, which are sources of heat (cold). As a rule, these sources are production wells and other facilities located at oil and gas fields (in Russia 93% natural gas and 75% oil are produced in permafrost). The developed model and the software codes can be used for long-term forecasting of changes in permafrost and deep layer of freezing (thawing) of soil (active layer thickness - ALT), in depending only with the climatic conditions, as an input for the software, in particular, with average temperature and intensity of solar radiation. An essential feature of this method is "binding" by the original algorithm to a specific geographic location, as determined by latitude and longitude. The software is designed for multi-processor computer systems and will be adapted to the "cloud" technology.

1 Introduction

Before starting development of oil and gas fields in areas of permafrost distribution, according to the approved standards, it is required to carry out a large series of numerical calculations for modeling of temperature fields in frozen soil from various sources of heat (for example, production wells), or cold (cooling devices) for soil thermostabilization. Particularly, in drilling sites designing a thawing radius (a zero isotherm from the well lower than layer of seasonal changes of temperature in soil) has to be found for all times of operation of the well for 30 years. A three-dimensional mathematical model [1, 3] considering the most essential factors, influencing on distribution of temperature fields in soil, a numerical algorithm and software packages "Wellfrost" and "TermoFrost" ("TermoFrost" package is focused on cloud computations with using super computer) are developed for this purpose. The software packages were tested for eight Russian oil and gas fields located in a zone of permafrost. The computed results are in a good agreement with experimental data. Usually simulation of thermal fields has to be processed in a large three-dimensional computational area (up to 100 meters) therefore a detailed grid is required for providing necessary accuracy. Its size determines a processing time of calculation and requirements to the characteristics of computer. It is necessary to carry out remote calculations with using large-nodes computer complexes and to develop "in the clouds" technologies for organization of numerical calculations for the users, who aren't possessing special knowledge of organization of such calculations. Particularly, a climatic dataset (with respect to the open NASA databases) was developed to make it easier the process of input of the initial

parameters which are responsible for climatic characteristics, corresponding to the chosen latitude and longitude. This climatic base is included in the cloudy interface.

2 Mathematical model

First let consider heat exchange on a flat ground surface directly illuminated by the sun. Let the initial time be $t_0 = 0$, and the ground is a box Ω and has a temperature $T_0(x, y, z)$. The computational domain is a three-dimensional box, where x and y axes are parallel to the ground surface and the z axis is directed downward. We assume that the size of the box Ω is defined by positive numbers L_x, L_y, L_z: $-L_x \leq x \leq L_x$, $-Ly \leq y \leq L_y$, $-L_z \leq z \leq 0$. Let $T = T(t, x, y, z)$ be soil temperature at the point (x, y, z) at the time moment t. The main heat flow associated with climatic factors on the surface $z = 0$ is shown in Figure 1.

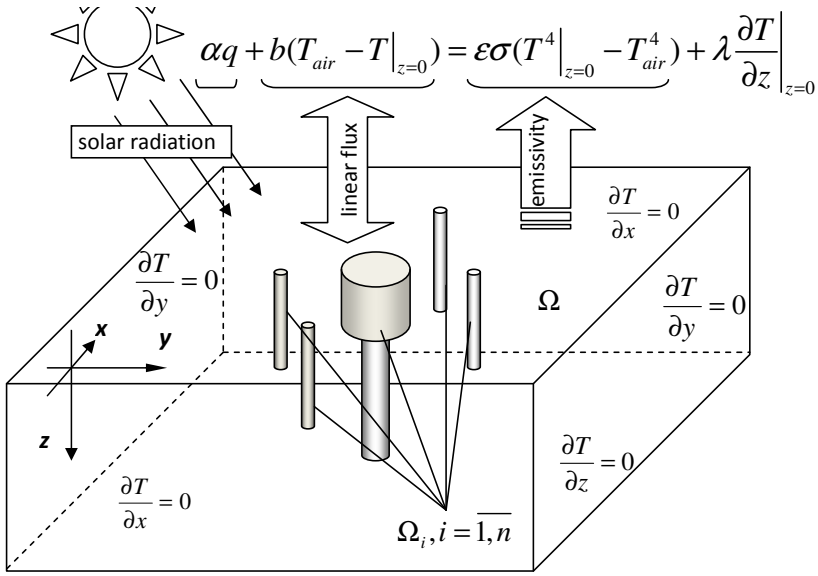

Figure 1: The main heat flows and boundary conditions.

$T_{air} = T_{air}(t)$ denotes the temperature in the surface layer of air, which varies from time to time in accordance with the annual cycle of temperature; $\sigma = 5,67 \cdot 10^{-8}\ Wt/(m^2K^4)$ is Stefan-Boltzmann constant; $b = b(t, x, y)$ is heat transfer coefficient; $\varepsilon = \varepsilon(t, x, y)$ is the coefficient of emissivity. The coefficients of heat transfer and emissivity depend on the type and condition of the soil surface. Total solar radiation $q(t)$ is the sum of direct solar radiation and diffuse radiation. Ω can include a number of engineering structures. Suppose that in Ω there are n objects that are heat sources (for example producing insulated wells, pipelines). We denote the surface of these objects by $\Omega_i = \Omega_i(x, y, z)$, $i = 1, ..., n$ (Fig.1).

Thus, the modeling of thawing in the soil is reduced to the solution in Ω of the equation following heat equation [2, 3]:

$$\rho\big(c_\nu(T) + k\delta(T - T^*)\big)\frac{\partial T}{\partial t} = \mathrm{div}\,(\lambda(T)\mathrm{grad}T), \tag{1}$$

where ρ is density $[kg/m^3]$, T^* is temperature of phase transition $[K]$,

$$c_\nu(T) = \begin{cases} c_1(x, y, z), & T < T^*, \\ c_2(x, y, z), & T > T^*, \end{cases} \text{ is specific heat [J/kg K]},$$

$$\lambda(T) = \begin{cases} \lambda_1(x,y,z), & T < T^*, \\ \lambda_2(x,y,z), & T > T^*, \end{cases} \text{ is thermal conductivity coefficient [Wt/m K],}$$

$k = k(x, y, z)$ is specific heat of phase transition, δ is the Dirac delta function.

Thus, it is necessary to solve equation (1) in the area Ω with initial condition

$$T(0, x, y, z) = T_0(x, y, z). \tag{2}$$

and boundary conditions

$$\alpha q + b(T_{air} - T_{z=0}) = \varepsilon\sigma(T^4_{z=0} - T^4_{air}) + \lambda\frac{\partial T}{\partial z}, \tag{3}$$

$$T\Big|_{\Omega_i} = T_i(t), i = 1, \ldots, n, \tag{4}$$

$$\frac{\partial T}{\partial x}\Big|_{x=\pm L_x} = \frac{\partial T}{\partial y}\Big|_{y=\pm L_y} = \frac{\partial T}{\partial z}\Big|_{z=\pm L_z} = 0. \tag{5}$$

Thus, the simulation of heat transfer in three-dimensional domain with the phase transition is reduced to solving the initial-boundary value problem (1)–(5).

The base of this numerical method is an algorithm with good reliability in finding thermal fields of underground pipelines [4, 5], but in view of specificity, related to the possible phase transitions in the soil [1, 3].

3 Numerical results

Let consider computational results for two different engineering facilities affecting the thawing of permafrost. The object of simulations is a single production well wich diameter is 178 mm. The construction has no special thermal insulations. The base temperature of permafrost is -0.5°C.

In Figure 2 the thermal fields in the soil are shown up to the depth of 22 meters for the well, which has been in operation during 5 years, and two months (April and October) are observed. Two temperatures in the wells are presented: 40°C and 70°C. We can determine a radii of thawing which depends on the temperature of the well and equals 7.66 m for the first temperature and 9.63 m for the second one at the depth of 22 m.

Figure 3 shows cloud interface form which is used to carry out computations with using mobile device (e.g., an internet mobile phone) connected via a server with super-computers, that hosts the Wellfrost program code. As a result of remote calculations a necessary data set could be obtained for long-term forecasting of changes in the permafrost. A target device is necessary to have an access by a mobile device.

Therefore, these results enable us to make long-term forecasts for the thawing of the permafrost around the various engineering systems according to different climatic and physical factors.

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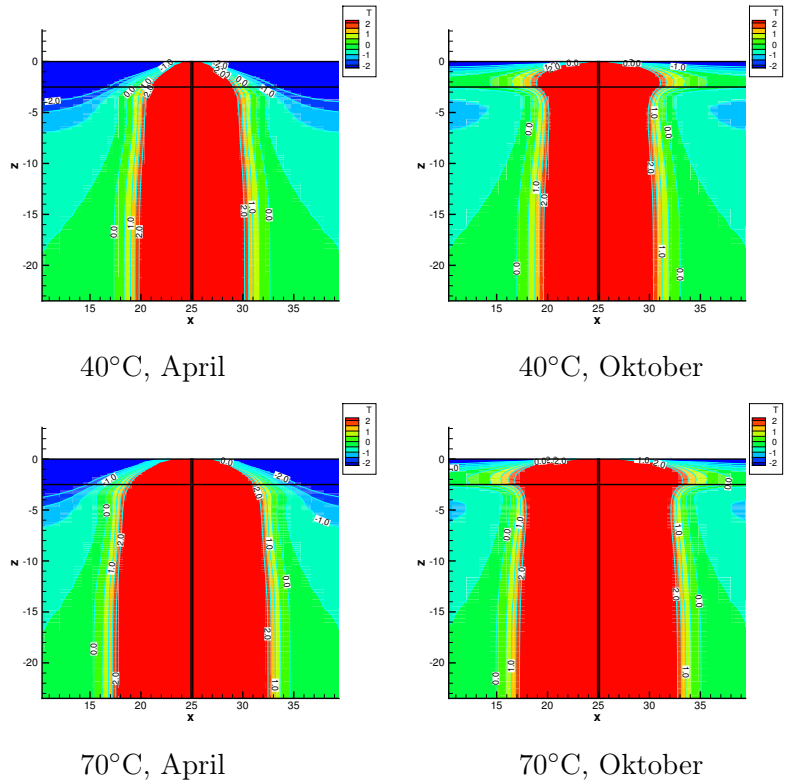

Figure 2: Thermal fields around a well with no isolation for different temperature of the well, 5 years of exploitation.

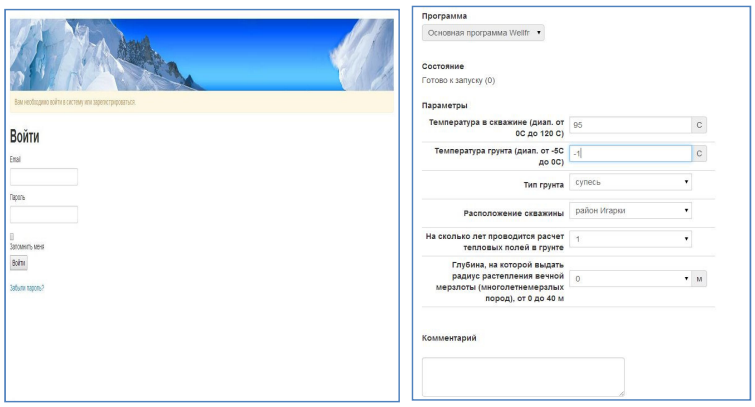

Figure 3: Wellfrost cloud forms.

References

[1] Mikhail Yu. Filimonov and Nataliia A. Vaganova. Proc. ASME. 45158, Volume 4: Pipelining in Northern and Offshore Environments; Strain-Based Design;

Risk and Reliability; Standards and Regulations 133 (September 24, 2012), (doi: 10.1115/IPC2012-90287).

[2] M.Yu. Filimonov, N.A. Vaganova. Simulation of Thermal Fields in Permafrost around Engineering Constructions in Presence of Seasonal Cooling Units // Proceedings of XLI Summer School-Conference "Advanced Problems in Mechanics" 1–6 July, 2013. St. Petersburg. 2013.

[3] Vaganova N.A., Filimonov M.Y. Simulation of Engineering Systems in Permafrost. Vestnik Novosibirskogo Gosudarstvennogo Universiteta. Seriya Matematika, Mekhanika, Informatika Computational technologies. **13**, 4, 2013.

[4] Bashurov V.V., Vaganova N.A., Filimonov M.Y. Numerical simulation of thermal conductivity processes with fluid filtration in soil. Computational technologies. **16**, 4, 2011.

[5] N. A. Vaganova. Existence of a solution of an initial-boundary value difference problem for a linear heat equation with a nonlinear boundary condition. Proceedings of the Steklov Institute of Mathematics, **261**, 1, 2008.

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