NUMERICAL MODELING THERMAL STABILIZATION OF SOILS IN REGIONS OF THE FAR NORTH WITS THE HELP OF THERMAL SIPHONS AND SEASONAL FREEZING DEVICES

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Abstract

It is considered a pipe of the single seasonal cooling device working in a file of a ground which during winter time is frozen completely, and in summer it thaws on small depth. For modelling process the numerical step-by-step method of elementary volumes is used. The concept of effective factor of transfer of heat from a file of a ground to atmospheric air is used. Continuous process of work of a pipe during lines of months, both in winter, and in summertime is modelled.

KEYWORDS

The seasonal cooling device, permafrost, phase transition, climate, modeling, numerical method.

INTRODUCTION

Problems of thermal stabilization and freezings of soils get now rather an actual meaning for the following reasons: intensive development of regions of the Far North and other areas of a "eternal" frozen ground, necessity of prevention of degradation of a frozen ground at various technical influences and owing to the general warming a climate. These processes have difficult nonlinear multifactorial character as in thermodynamic sense soils represent heterogeneous multicomponent multiphase systems. The reliable method of modelling of such processes is necessary for the decision of a problem in concrete real geological and climatic conditions with the account of "feedback", that is influence of an environment on work of the freezing or stabilizing device.

THE METHOD OF ELEMENTARY VOLUMES

The method of elementary volumes (EVM) represents a numerical step-by-step method at which time is broken into so small intervals and a body on so small areas (elementary volumes or cells), that to the description of non-stationary physical processes it is possible to apply elementary physical laws. The form of area and dimension of a problem can be anyone. The form of cells can be any. At the decision of a problem of heat conductivity on border of area anyone are realized, generally non-stationary and nonlinear, boundary conditions.

On a way of digitization of area EVM it is similar to a method of final elements (FEM), and it can be applied together with it, for example, at the joint decision of problems of heat conductivity and problems of mechanics. Small areas in EVM it is expedient to name cells as for them are not concretized position of sites, functions of the form and others, inherent FEM concepts. In EVM, as well as in a known method of control volumes, laws of preservation both inside each cell, and for area as a whole are carried out. However EVM is not a net method. Instead of differential or final differences the equations in it the physical laws underlying these equations are used, as a rule. So at the decision of a problem of heat conductivity the first beginning of thermodynamics, law Fourier and the law of Newton are used. For realization of a method the system of universal programs for computers of a modern level is developed.

EVM can be applied and to modelling other physical processes in which the status of a cell on each small step on time depends on a status of environmental cells and from some other, fixed at present time, parameters (diffusion, heat and weights exchange, migration of a moisture, etc.).

The general problem of the description of work thermal stabilization and freezing devices can be broken on two interconnected parts: internal heat problem describing processes in a pipe, and external heat problem describing processes in a file of a ground. In the given work the basic attention is given to the decision external problems. However, the general method can be used and at the decision of an internal problem if physical laws and boundary conditions will be correctly enough formulated.

The method is realized in system of programs FSTM (Freezing soil technology modeling), which allows to solve the broad audience of engineering and scientific problems.

NOT ISOTHERMAL PHASE TRANSITION

Production of a problem

The phase transitions of the first sort accompanying with allocation or absorption of latent heat and change of volume are considered. These transitions on complexity of process are divided on two groups: transitions at the fixed value of temperature and transitions which occur in wide enough range of temperatures. In the first case phase transition can be named ***isothermal*** (IPT) and in the second - ***not isothermal*** (NIPT). At freezing heterogeneous environments phase transitions have complex character as at downturn of temperature, as a rule, occurs gradual freezing waters. At formation of ice in the nature on process of phase transformation the set of the reasons influences [1].

In many cases the solution, passing in a firm status, loses uniformity and allocates pure ice. Thus the solution becomes more concentrated and the temperature of its freezing changes. Such processes occur in many soils. Therefore in permafrost problems all phase transitions, strictly speaking, concern to the second group [2].

At modelling phase transitions a status of environment(Wednesday) we shall characterize in parameter of a status θ: $\theta = 0$ - environments it is not frozen, $\theta = 1$- environment is frozen completely. Generally, at NIPT, this size depends on temperature.

Isothermal phase transition occurs at the fixed value of temperature t_f.

At this temperature there is a change of parameter θ, and at other values – change of temperature. Increments of temperature and parameter of a status are defined(determined) by expressions:

$$dt = \frac{dq}{c_c}, \qquad d\theta = -\frac{dq}{w}, \tag{1}$$

where c_c – a thermal capacity, w – the latent heat of fusion of a cell.

Not isothermal phase transition (fig. 1) occurs in a range of temperatures $[t_{pb}, t_{pt}]$. Inside this interval the status of environment is defined by experimental dependence

$$\theta = \theta(t). \tag{2}$$

NIPT it is possible to present as a trajectory of movement on a curve $\theta = \theta(t)$.

At NIPT the thermal stream acting in a cell on the given step in time $d\tau$, it is possible to present as the sum of two components:

$$dq = dq_p + dq_t, \tag{3}$$

where dq_p – the heat spent on phase transition, dq_t - the heat spent on change of temperature.

Then from (1) and (3):

$$d\theta = -\frac{dq_p}{w}, \qquad dt = \frac{dq_t}{c_c}, \tag{4}$$

$$\frac{d\theta}{dt} = -\frac{dq_p c_c}{dq_t w}, \tag{5}$$

$$dq_p = \frac{p}{1+p}dq, \qquad dq_t = \frac{1}{1+p}dq, \qquad p = -\frac{w}{c_c}\frac{d\theta}{dt}. \tag{6}$$

Dependences (1)–(6) are put in a basis of algorithm which allows to model both freezing, and thawing sois. Thus, at the decision of a specific target for each ground it is necessary to set function $\theta = \theta(t)$ which turns out as a result of laboratory researches soils. At the numerical decision of a problem(task) each of such dependences can be set by set of the values, that is a file $[t_k, \theta_k]$, where t_k and θ_k - values in sites of a grid with any step.

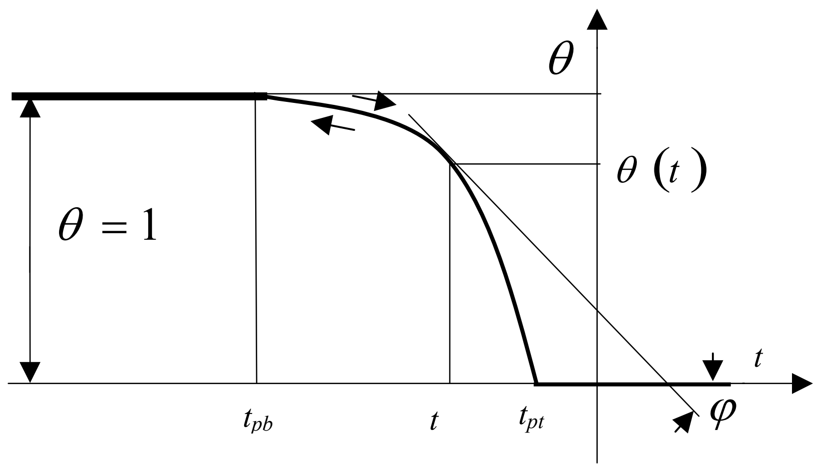

Fig. 1. Not isothermal phase transition

MODELLING OF WORK OF THE COOLING DEVICE

Production of a problem

The single seasonal cooling device of any design which cools a ground in a cold season is considered, transferring heat from a ground in an atmosphere. In a file of a ground there is a vertical pipe. It works in that case when the temperature of air is negative. Extremely simplifying this complex process of transfer of heat, it is possible to present it as three stages:

1) transfer of heat from a ground to pipe;
2) transfer of heat inside seasonal the cooling device;
3) and transfer of heat to an atmosphere.

Thus, the description of these three stages is reduced to the decision of three problems connected among themselves. In the given work the decision of the first problem as the purpose of work is modelling such processes in concrete real geological and climatic conditions with the account of "feedback" is considered, that is in view of influence of an environment on work of the cooling device.

For simplification of a problem as a whole the concept of effective factor of transfer of heat from a file of a ground to atmospheric air is used [8]. It allows on border a pipe – a ground to formulate boundary conditions of the third sort.

Characteristics of a pipe

The steel pipe has diameter of 0.1 m. and thickness of a wall of 3 mm. Factor of heat conductivity - 50 $W/(m \cdot K)$. Effective factor of a heat transfer – 20 $W/(m^2 \cdot K)$. Depth of immersing of a pipe – 8 m.

Characteristics of a climate

Characteristics of a climate are accepted for peninsulas Yamals (table 1).

As work of the cooling device is modelled during all cold season, monthly average values are used.

Table 1. Characteristics of a climate on months of year.

Months	Average temperature, ºC	Thickness of a snow cover, m.	Speed of a wind, m/s.	Temperature on a surface of a ground, ºC *
January	-23.9	0.35	4.6	-12.0
February	-22.8	0.40	4.6	-14.0
March	-18.3	0.30	4.6	-13.9
April	-9.0	0.30	4.3	-9.6
May	-1.5	0.10	3.9	-2.6
June	8.6	0.0	3.9	3.1
July	14.7	0.0	3.9	9.1
August	11.4	0.0	4.1	7.9
September	5.5	0.0	4.2	3.9
October	-4.5	0.10	4.4	-1.7
November	-17.2	0.20	4.6	-4.3
December	-22.8	0.25	4.6	-9.6

* By results of calculation.

Characteristics of a ground

Characteristics of a ground are accepted for enough humidified sandy loam that is typical for the given area (table 2). During winter time all ground is in the frozen status. In summertime the top layer thickness 1.0–1.5 m thaws.

Table 2. Characteristics of a ground

The name	Dimension	Size
Density	kg/m^3	2000
Humidity	%	30
Temperature of freezing	^0C	-0.3
Heat conductivity of a thawed ground	$W/(m \cdot K)$	1.4
Heat conductivity of a frozen ground	$W/(m \cdot K)$	1.7
Thermal capacity of a thawed ground	$J/(m^3 \cdot K)$	1.4
Thermal capacity of a frozen ground	$J/(m^3 \cdot K)$	1.2

Modelling of long-term process

The period by duration three years, since January is considered. In first half-year СОУ does not work, and consequently in a ground the natural status responding the given climatic conditions (Fig. 2) is formed. This stage is necessary that Seasonal freezing devices (SFD) began to work at naturally possible entry conditions.

a) A scale of the image of temperature fields

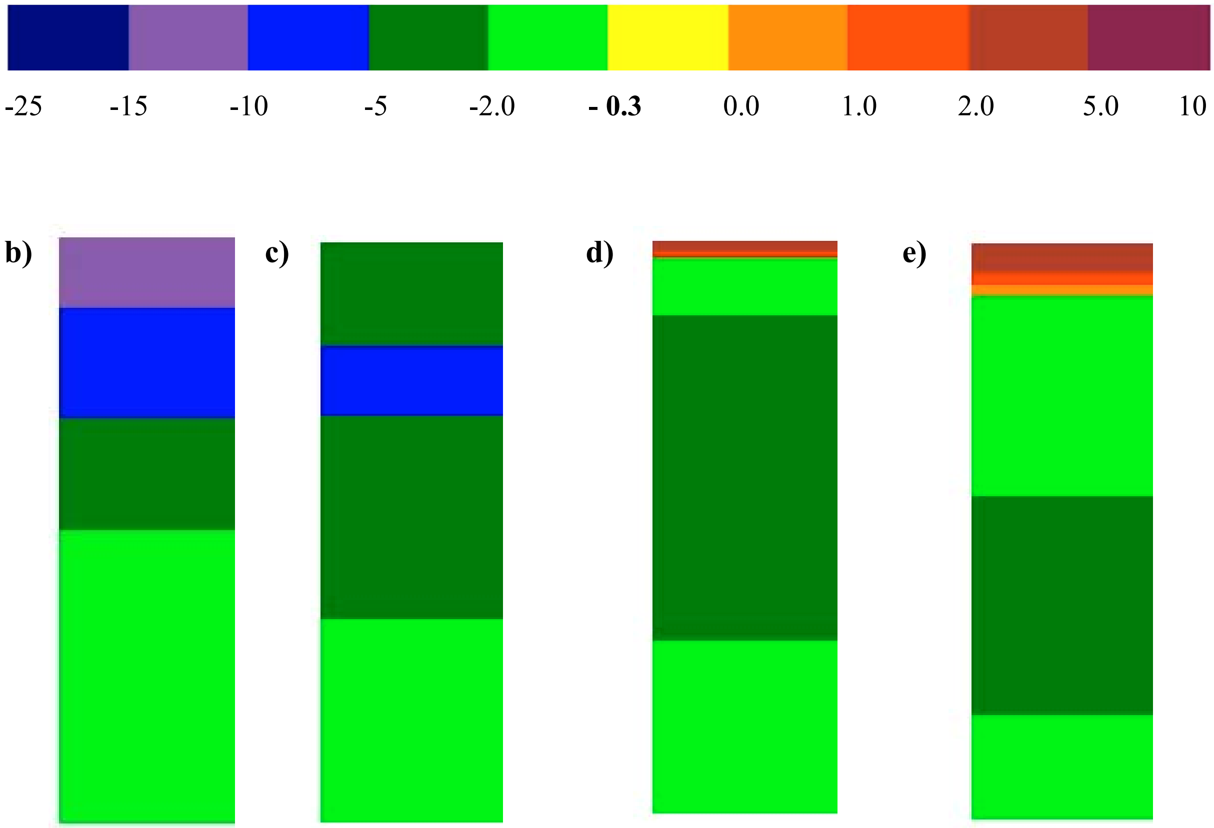

Fig. 2. Natural climatic distribution of temperature on depth: a – a scale of the image of temperature fields, b – March, c – April, d – June, e – August

The scale of colors will consist of two sites, border a freezing point (or for NIPT – the point started freezing). To the left of this point the zone of the low temperatures, responding the frozen ground, and on the right – responding a thawed ground is located. Borders of color strips are isotherms which are appointed any way depending on specificity of a problem. So in our case the isotherm - 0.3 ^{0}C divides zones of the frozen and thawed ground.

Pipe starts to work in October when the temperature of air becomes negative. By the end of October on the part of a pipe the zone of low temperatures up to -5 ºC (distributes Fig. 3 a). However in the top part the strip of a thawed ground is kept. In November in a ground the temperature goes down, however in the top part the narrow strip of a thawed ground (Fig. 3 b) is kept. Further around of a pipe the temperature goes down, and the field of low temperatures up to -15 ºC is formed and is lower. However in April the temperature of external air raises, and the pipe starts to work on rise in temperature of a ground (Fig. 3 e). Such mode proceeds in May (Fig. 3 f). At approach of warm time the pipe ceases to work, and by the end of June indignation of a temperature field around of a pipe completely disappears (Fig. 4 a). Further in the top layers of a ground the zone of a thawed ground, about same, as well as one year ago is formed, however in depth the zone of temperatures is lower - 2 ºC borrows all space on depth from 3 m. and more (Fig. 4 b, c).

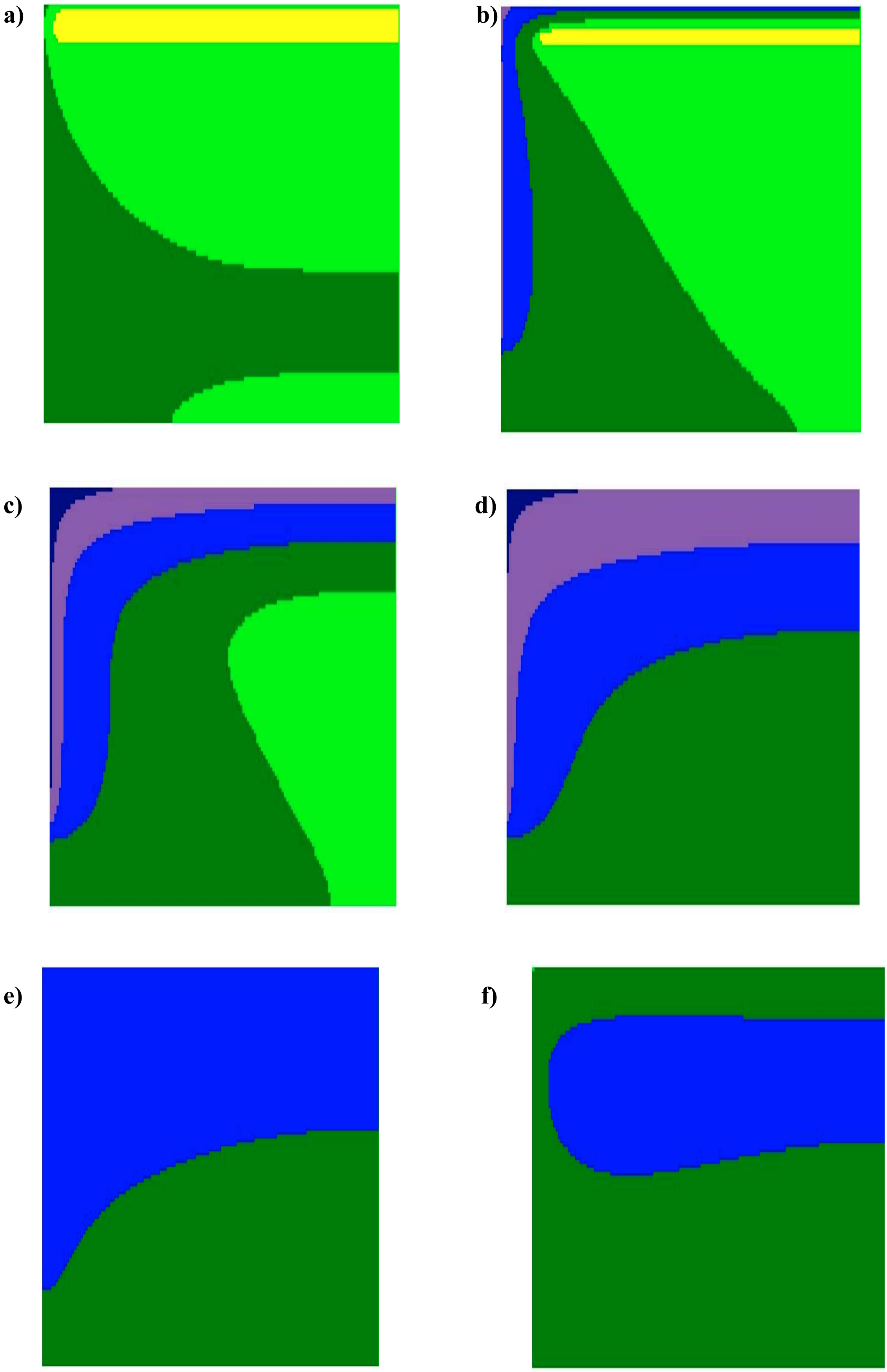

Fig. 3. Fields of temperature: a – October, b – November, c – January, d – March, e – April, f – May

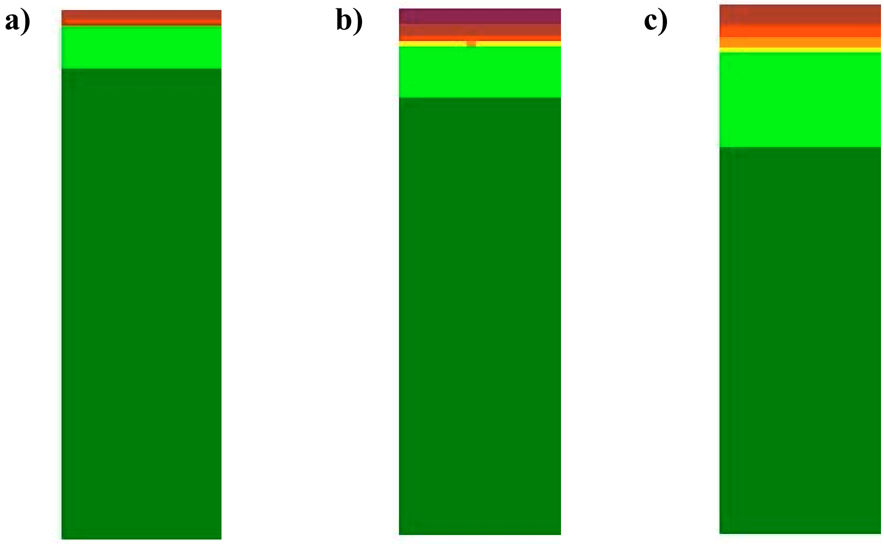

Fig. 4. Distribution of temperature on depth in the summer of the second year: a – June, b – July, c – August

As change of temperature of air within one year has the periodic character, natural change of temperature of a ground has wave character: waves warm in the summer and cold are distributed from a surface in depth in the winter. Precisely also, in an operating time of a pipe of a wave are distributed in a radial direction. However, an outline their more complex, as temperature of a ground переменна on height. Imposing of these two processes also forms a temperature field in a file of a ground.

CONCLUSION

Numerical modelling of work СОУ during all cold season and the next months shows, that the processes proceeding in a ground, contacting to a surface of a pipe have complex character. In model of system used above as a whole a number of simplifying assumptions is accepted. The most essential is application of the general equivalent factor of a heat transfer. Thereof the thermal stream through a wall of a pipe becomes proportional to a difference of temperatures of atmospheric air and adjoining to a pipe of a ground. Therefore through a surface of a pipe the direction of a stream of heat on different sites of a pipe can be various. Influence of this circumstance on work СОУ as a whole can be estimated, only considering internal processes, that is beyond the problem put above.

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