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THE PROSPECT OF USING THERMAL FIELD IN THE SOIL

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An algorithm allowing the simulation of thermal fields in soils under different natural climatic conditions and in soils with different thermal conductivity has been defined. The depth of annual temperature oscillations in soil has been established by the example of climatic conditions of the Zaporozhye region.

In doing so, first and foremost we need to calculate the temperature field of soil (that is to say, in the absence of thermal action on the soil of ground heat exchange system), which will be taken into account in the simulation of technological processes and technical systems capable of using geothermal energy.

There has been developed an algorithm allowing the simulation of the temperature field in soils under various natural climatic conditions and in soils having different coefficients of thermal conductivity. It has been established that under climatic conditions of Zaporozhye region annual soil temperature fluctuations reach the depth z = 9–17 m. Obtained results will be used for simulation of technology processes with technical facilities designed for use of geothermal energy.

Key words**:** soil, thermal field, soil thermal conductivity, depth.

Introduction. The maintenance of optimal microclimate in animal houses entails a significant consumption of energy and costs. It is impossible to achieve a cheap and high quality livestock product in short space of time without keeping optimal microclimate conditions in animal houses. The microclimatic impact consists of combined effect of the temperature, air humidity, air gaseous composition and air pollution. One way to increase the efficiency in livestock production is cutting down the costs of maintaining these conditions, using alternative energy sources, and in particular - geothermal energy.

For the rational use of potential energy of soils with the application of technical equipment, having ground heat exchangers as working elements, it is necessary to determine the temperature field formed by various factors (fig. 1).

The reference [5] provides the following expression for thermal field in soil that allows us to consider Earth's radiogenic heat flow:

$$T_г(z,t) = A_T\ e^{-z\sqrt{\frac{\pi}{a_г\Theta}}} \sin\left(\frac{2\pi}{\Theta}t - z\sqrt{\frac{\pi}{a_г\Theta}}\right) + \varphi(z) \quad , \tag{1}$$

where:

$T_г(z,t) -$ the soil temperature at time t and depth z, °C;

A_T – amplitude of the soil surface temperature (at $z = 0$), °C;

$a_г$ – thermal conductivity of the soil, m^2/month;

Θ – amplitude cycle, Θ = 12 months;

$\varphi(z)$ – function describing the distribution of temperature in the ground with depth at the initial moment of time, which can be used to calculate Earth's radiogenic heat flow.

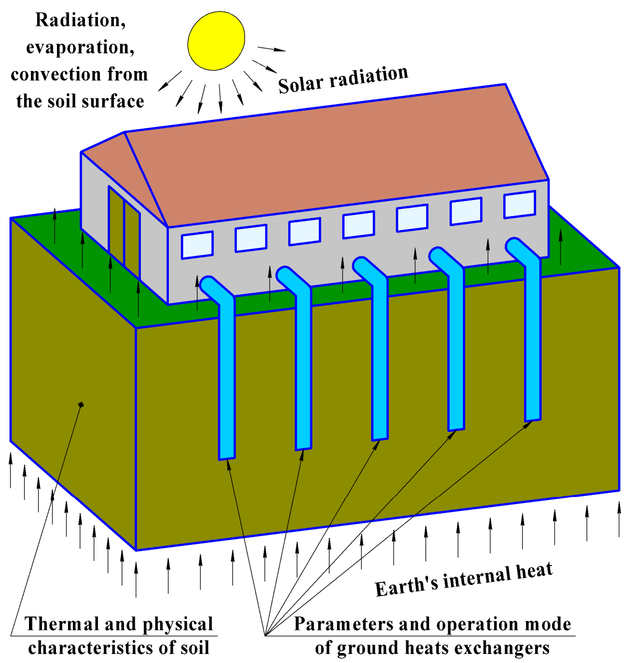


FIg. 1. **Soil thermal field forming factors**

The problem was solved with given initial condition: $T_г(z,0)=\varphi(z)$ and boundary conditions: $T_г(\infty,t)=0$; $T_г(0,t)=A_T \sin\left(\frac{2\pi}{\Theta}t+t_0\right)$, where t_0 – the initial phase.

However, the above reference does not provide a detailed derivation of the expression (1), and what is more, the derived expression satisfies neither the initial condition nor the boundary conditions at the soil surface, what can be proved by direct substitution.

The purpose of the research was to simulate technological processes and technical systems that can use geothermal energy.

Material and methods. The analysis is performed on the basis of generally accepted approaches for thermal conductivity of solids, heat transfer from one solid particle to another when they are in contact, the molecular thermal conductivity in the environment [5].

Results and their discussion. Simulation of heat and mass transfer, which is a factor of thermal field formation in such a multi-component system as soil, is a highly complicated task because of the necessity of considering, mathematical description and implementation of various mechanisms: thermal conductivity of solids, heat transfer from one solid particle to another upon their contact, molecular thermal conductivity of the medium that fills the space between solids particles, convection of steam and water occupying the pore space, and so on. Strictly speaking, besides the aforesaid mechanisms, the simulation of soil thermal field requires the consideration of chemical and mineralogical characteristics of the soil skeleton, mechanical properties of solids, dispersion degree in porous medium, shape and size of solids and pores, number of phases, quantitative relationship between phases and their relative position in the porous medium and many other physical and chemical parameters of the soil. The detailed consideration of the aforesaid factors in simulation of soil thermal fields represents a serious problem [6].

However, applying the model of equivalent thermal conductivity we can to describe those processes accurately enough by means of the parabolic partial differential equation using equivalent coefficients [7]. In this case, the soil is considered as a quasi-homogeneous body for which an ordinary heat conduction equation, relating temperature $T_г$, time t and depth z, can be applicable.

$$\frac{\partial T_г}{\partial t} = a_г \frac{\partial^2 T_г}{\partial z^2}. \qquad (2)$$

The soil thermal field can be determined based upon a solution of the basic equation (2) with preset boundaries, that is the initial and boundary conditions.

The initial condition is defined by using the function of temperature distribution with depth of the earth at the initial moment of time:

$$T_г(z,0) = T_{г0} + k_T z, \qquad (3)$$

where:

$T_{г0}$ – average annual temperature at the soil surface, °C;

k_T – the rate of temperature increase with depth depending on the rate of Earth's radiogenic heat flow, can be taken as k_T = 0,03 °C/m for thermal conditions of Ukraine.

Boundary conditions expressing the law of soil-environment interaction interactions, should be formulated as two soil boundaries.

The boundary condition at the soil surface can be written as follows:

$$T_г(0,t) = T_{г0} + A_T \sin\left(\frac{2\pi}{\Theta} t\right). \qquad (4)$$

The amplitude of temperature oscillations decay with depth, and when the value $z \geq Z$, is reached, the soil temperature remains practically unchangeable in the prescribed time interval, that allows the setting of the following boundary condition [7]

$$T_г(Z,t) = T_{г0} + k_T Z = const. \qquad (5)$$

According to the reference [8], annual temperature-oscillations decay in amplitude towards zero at a depth of 30 m in polar latitudes, at a depth of 15-20 m in mid-latitudes, and about 10 m in tropical latitudes (where annual amplitudes have lower values then in middle latitudes). At these depths the annual soil temperature remains constant.

Therefore, Z = 100 taken for the boundary condition (5) will guarantee the absence of temperature oscillations at this depth and lead to lower computational costs to an acceptable level.

The soil surface temperature for Zaporozhye region was determined as a function of time using [9] and based on the approximation of long-term data (fig. 2),

$$T_г(0, t) = 12{,}0 + 15{,}2\,\sin\left(\frac{2\pi}{12}t + 4{,}15\right). \quad (6)$$

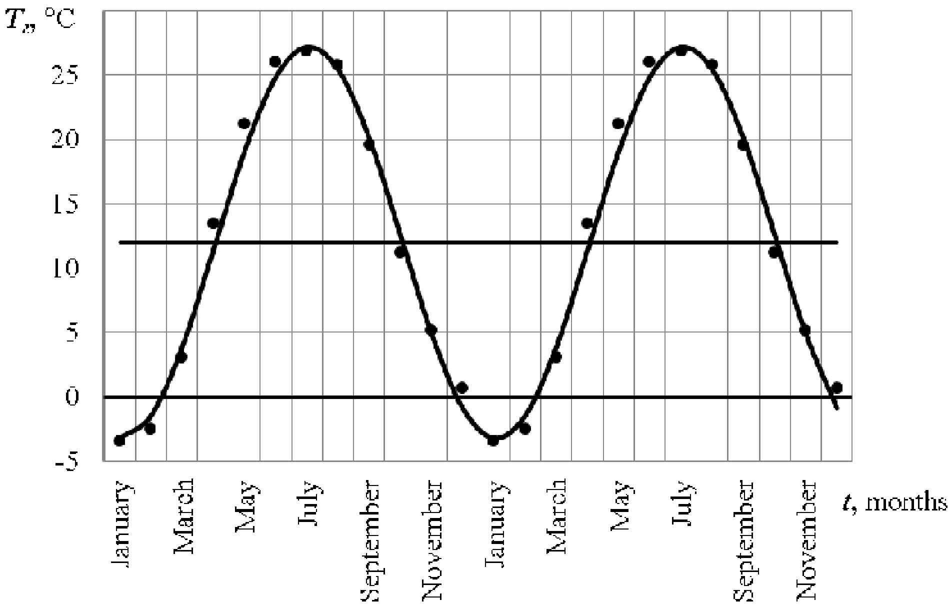
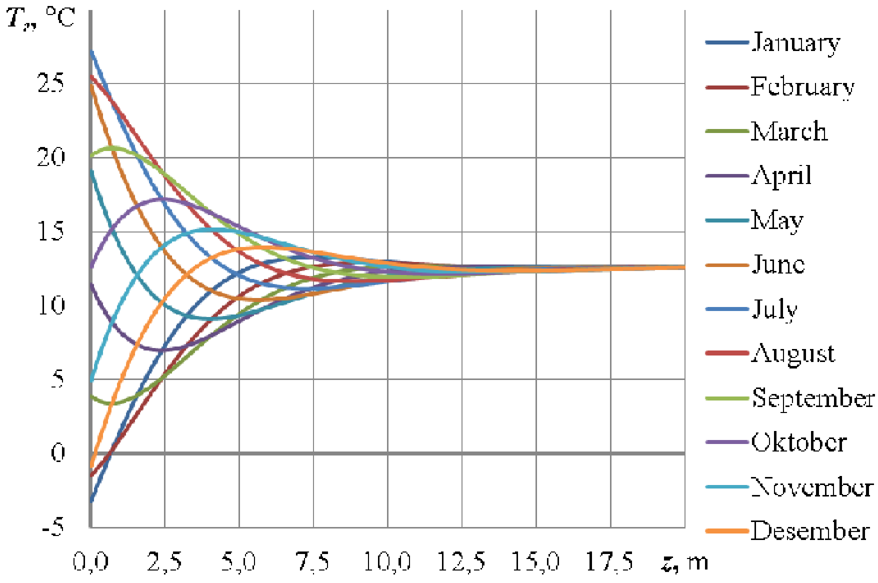


Fig. 2. **Soil surface temperature according to long-term data for Zaporozhye region**

The expression (6) contains the initial phase of temperature oscillations equal to 4,15 months. Therefore, in simulation of the soil thermal field with the use of the initial condition (4) not including the initial phase, we set approximately April 20 (see pic. 2) as the process start date for Zaporozhye region (not January 15 because we only have the average monthly temperature data at soil surface). That is to say, for natural climatic conditions of Zaporozhye region the annual average temperature at soil surface is determined as of April 20.

With increasing soil density and moisture content thermal conductivity increases, temperature oscillations become faster and penetrate more deeply into soil. According to the reference [10], soil thermal conductivity coefficient $a_г$ = 0,76-2,67 m^2/month, and at the same density and moisture content, it is also dependent upon soil type. For example, sand has the highest coefficient of thermal conductivity, sandy loam – somewhat less, and loam has the lowest value.

Having solved the equation (2) with the boundary conditions (3), (4), (5) using numerical method and taking into account the initial phase t_0, we obtained the dependence of soil temperature on time and depth as shown on the figure 3.



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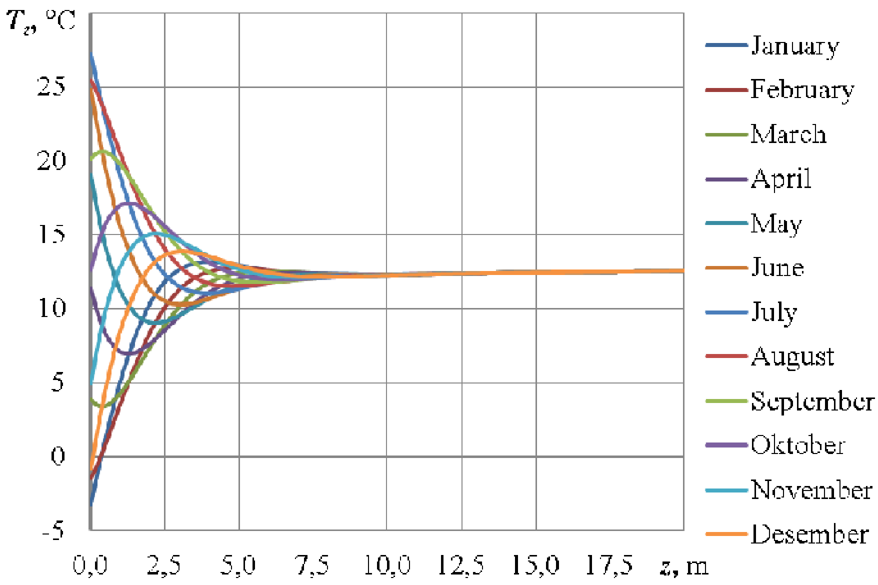

b

Fig. 3. **Soil temperature T_z in various months of a year, depending upon depth z with coefficient of thermal conductivity a_z = 2,67 m^2/month (a) and a_z = 0,76 m^2/month (b)**

As shown in the drawing 3, annual soil temperature oscillations can penetrate to depth z = 9-17 m under natural climatic conditions of Zaporozhye region.

Therefore, there is an algorithm allowing the simulation of a soil thermal field:

1) To determine the coefficient k_T , that takes into account the increase in temperature with depth.

2) To approximate long-term records of soil surface temperature by means of the following type of function $T_г(0,t) = T_{г0} + A_T \sin\left(\frac{2\pi}{\Theta}t + t_0\right)$.

3) To determine the soil thermal conductivity coefficient $a_г$ related to the type, density and moisture of soil.

4) To solve the equation (2) with boundary conditions (3), (4), (5) taking into account the initial phase t_0.

Conclusions

There has been developed an algorithm allowing the simulation of the temperature field in soils under various natural climatic conditions and in soils having different coefficients of thermal conductivity. It has been established that under climatic conditions of Zaporozhye region annual soil temperature fluctuations reach the depth z = 9-17 m. Obtained results will be used for simulation of technology processes with technical facilities designed for use of harness geothermal energy.

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ПЕРСПЕКТИВА ВИКОРИСТАННЯ ТЕПЛОВОГО ПОЛЯ В ГРУНТІ

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Наведено алгоритм, який дозволяє моделювання теплових полів в ґрунтах у різних природно-кліматичних умовах і на ґрунтах з різною теплопровідністю. Встановлена глибина річного коливання температури у ґрунті на прикладі природно-кліматичних умов Запорізької області.

Аналіз проведений на базі загальноприйнятих підходів щодо теплопровідності твердих тіл, теплопередачі від однієї твердої частинки до іншої при їх контакті, молекулярної теплопровідності в середовищі.

Розроблено алгоритм, що дозволяє моделювання температурного поля в ґрунті за різних природно-кліматичних умовах і на ґрунтах, що мають різні коефіцієнти теплопровідності. Було встановлено, що в кліматичних умовах р. Запоріжжя щорічні коливання температури ґрунту можливі в межах глибини 9…17 метрів.

Отримані результати будуть використані для моделювання технологічних процесів у технічних приміщеннях, призначених для використання геотермальної енергії.

Ключові слова: ґрунт, температурне поле, теплопровідність ґрунту, глибина.

ПЕРСПЕКТИВА ИСПОЛЬЗОВАНИЯ ТЕПЛОВОГО ПОЛЯ В ГРУНТЕ

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Приведен алгоритм, позволяющий моделировать тепловые поля в почвах при различных природно-климатических условиях и в почвах с разной теплопроводностью. Установлена глубина годичного колебания температуры в почве на примере природно-климатических условий Запорожской области.

Анализ проведен на базе общепринятых подходов по теплопроводности твердых тел, теплопередачи от одной твердой частицы к другой при их контакте, молекулярной теплопроводности в среде,

Разработан алгоритм, позволяющий моделировать температурные поля в почве при различных природно-климатических условиях и на почвах, имеющих разные коэффициенты теплопроводности. Было установлено, что в климатических условиях р. Запорожье ежегодные колебания температуры почвы возможны в пределах глубины 9...17 метров.

Полученные результаты будут использованы для моделирования технологических процессов в технических помещениях, предназначенных для использования геотермальной энергии.

Ключевые слова: грунт, температурное поле, теплопроводность почвы, глубина.

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