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THE CALCULATION OF THE COEFFICIENT OF HEAT CAPACITY AND HEAT TRANSFER OF MULTILAYER GROUND BY TAKING IN TO ACCOUNT DATA FROM THE EARTH SURFACE

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ABSTRACT

The equation of heat distribution in the inhomogeneous medium is being investigated. Approximate method for the calculation of heat transfer coefficient of multilayer ground is being elaborated. Priori estimates for solution of direct and conjugate different problems were obtained. The limitation of approximate value of heat transfer coefficient is being verified. Changes in the temperature of ground on the Earth surface are measured. The thermo physical characteristics of multilayer ground were identified in a laboratory condition. The numerical calculations were conducted with data on the Earth surface. Moreover, the heat transfer coefficient of rock was determined in the different areas of open mine of "Ekibastuzsky". Calculated data were compared with measured data.

Keywords: equation of thermal conductivity, inverse problem, direct problem, conjugate problem, priori estimates, thermo physical characteristics of ground.

INTRODUCTION

Disperse medium is a system, which consists of at least two phases. At the same time, one of these phases is distributed in the form of small sized particles in another phase. The substances with grained, cellular and fibred structure are important in technical ways; they are widely used in thermo energetics, ground management, construction, and coal and food industry. Furthermore, a large amount of household and natural powder-like materials are also related to this area. Usually the term "thermo physical characteristics" of disperse medium means a set of parameters which simultaneously characterises reaction of material in the process of heat and mass transfer. The thermal properties (C.Nerpin, A.Chudnovsky) like coefficient of thermal conductivity (λ), temperature conductivity (k) and volumetric heat capacity (C) are related. Currently, the investigation of thermal processes in materials is conducted in two ways (D.Kurtner, A.Chudnovsky).

1-way. Based on the solution of heat and mass transfer equation; the knowledge about thermal and mass transfer characteristics of material is required. This path is discovering more and more applications, but the practical implementation presently tied with considerable difficulties. In this case, it is necessary to take into account a large number of characteristics that vary widely depending on the structure of the material and experimental condition.

2-way. Based on the presentation of the material structure as a quasi-homogeneous body. The task of finding the temperature field is reduced to solving one heat equation, with the presence of variable thermal properties. In this approach, only thermal properties like λ, k and C are necessary. Naturally, such contraction of problem is inefficient since it is impossible to find simultaneously a field of humidity and temperature. However, there are clear advantages of using second principle: its relative simplicity, smaller number of required parameters, its ability to bring solutions to the operational form, which will be appropriate to solve a large number of engineering problems.

We will follow the second principle. In this work we propose a method for determining the coefficient of heat capacity and heat transfer of ground .This allows predicting geological composition of ground. The convergence of iterative process and the method of verifying limitation of heat transfer to the surrounding were proposed. The numerical calculation and results were compared with data from the laboratory and field.

BRIEF OVERVIEW (PREVIOUS RESEARCH)

The thermal conductivity process is a dominant for coarse material at moderate high temperature and humidity. This main simplification is essential for the construction of methods to measure thermo physical characteristics of dispersed materials.

The first direction was proposed by C.Maxwell (1873) by the method of general conductivity. He calculated the electric field of a system which consists of continuous isotropic mass. Moreover, extraneous particles with spherical shape are adjusted this isotropic mass. Burger H.C (1915) and Eucken A. (1932) investigated particles with more complicated shape and suggested an empirical formula for the calculation of thermal conductivity coefficient. Subsequently, by developing ideas of C.Maxwell scientists D.Bruggeman (1935), C.Bottcher (1945), D.Polder and Van Santen (1946) suggested other formulas that specified Burger – Eucken formula.

The principle of general conductivity is not enough efficient as it is based on the ideal model structures. On the other hand, by analysing the structures of real disperse material was efficient. The next scientists did research in this way. They are O.Krischer (1934), T.Schuman and V.Voss(1934), C.Hängst (1934), D.Starostin(1935), I.Austin (1939),W. Smith (1940), O.Vlasov (1941),K. Zichtenecker (1941),V.Bogomolov (1941), A.Franchuk (1941), R.Bernshtein(1948), I.Loeb (1954), B.Kaufman (1955), A.Lyalikov (1956), G.Serih (1958) and A.Chudnovsky (1954, 1976).

All these works lead to the formulas for the thermal conductivity of the disperse system. It expresses them as a function of the size of pores or particles and thermal conductivity of the intermediate medium from the total porosity system._However, almost all computational techniques give significant differences from the experience (A.Chudnovsky, 1976).

Current approaches to the problem of providing a given thermal state of the technical systems require extensive application methods of mathematical and physical modelling. However conducting mathematical modelling is impossible without reliable information about external thermal impact on analysing object. Thus, the development of already existing and the creation of new technical objects are required elaboration of modern and more effective methods as well as resources of thermal regimes of construction, aggregates and system.

In the majority of practical cases, a direct measurement of thermal state (condition) and external thermal impact on a complicated construction is impossible. The only way to overcome these difficulties is indirect measurements. The mathematical approach is formulated as a solution of inverse problem by direct measurements of a system's certain properties. For example, temperature at discrete points. This requires the determination of a thermal state as a whole or a certain properties of a system. Presently there are so many publications on thermo physical measurements and devices. They are O. Aliphanov(1973), S. Budnik,b V. Mihailov, A. Nenarokomov (2006), E. Kartashov (2001), G. Kuznecov, V. Polovnikov (2006), V. Kuchin, S. Pyralishvilli (2006). These books briefly describe distinctive features of considered methods and measured devices. However, there are rarely discussed original mathematical model s of a considered thermo physical methods and devices.

The differential equation of thermal conductivity is a mathematical relationship usually expressed with partial derivatives, which characterise flow of physical phenomenon of heat transfer. In addition, it enables to calculate the temperature field at any interior point of a body at any time.

The differential equation of a thermal conductivity in one-dimension case is

$$\gamma_0 c \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial \theta}{\partial z}\right)$$

In order to use this equation, boundary conditions are required which includes:

1) Value of the geometry of a considered body;
2) Value of the initial condition which determines the temperature distribution of a body at the beginning;
3) Value of first, second, third and fourth boundary conditions which define consistent patterns of a heat transfer at the boundary surfaces on a sample.

   The mixed boundary problem of a specific type is used in this work:

$$\begin{cases} \gamma_0 c \dfrac{\partial \theta}{\partial t} = \dfrac{\partial}{\partial z}\left(\lambda \dfrac{\partial \theta}{\partial z}\right) \\ \theta(0,t) = T_1, \quad \lambda \dfrac{\partial \theta}{\partial z}\Big|_{z=H} = -\alpha\left(\theta\big|_{z=H} - T_b(t)\right), \ \theta(z,0) = \theta_0(z) \end{cases}$$

In this case thermo physical properties of a ground are given $\gamma_0, c, \lambda, \alpha$ and initial temperature distribution $\theta_0(z)$, temperature of the atmosphere (air) on the Earth surface $T_b(t)$ and temperature of a soil at the boundary $z = 0$: $\theta(0,t) = T_1$. Besides, given the depth of study site H and the duration of time of an investigated section T. Analysis and development of methods for solving boundary value problems for the heat equation studied by A.Lykov and M.Myheev.

Currently, for solving boundary problems of a thermal conductivity equation are used not only analytical methods but numerical methods as well. The most of analytical solutions give a distribution of a temperature in a homogeneous medium. Processes of heat transfer in a complex environment are being modelled. Methods of finite-differences and finite elements were obtained mostly by using the numerical method.

Transition from continuous medium to some of its discrete medium is carried out in the finite-difference method. In this transition essential properties of a physical process should be preserved, especially the law of energy (heat) conservation. The difference schemes, according to the law of conservation, are called conservative. The works of .Ryhtmayer, K.Marton (1972), S.Godunov, V.Ryabenky (1977), A.Samarsky (1983) are dedicated for the analysis and elaboration of approaches to construct conservative difference schemes.

If there is required to find one of the parameters $\gamma_0, c, \lambda, \alpha$ then the inverse problem of thermal conductivity will exist (O.Alyphanov, 1973). The diverse inverse problem of a mathematical physics is being considered in various works. M.Lavrentiev, V.Romanov, S.Shishatsky (1980) and V.Romanov (1984) mainly pay attention to the problem of uniqueness of the solution and selection of classes with conditional correctness of problems. The most complete development of inverse problems for the equation with partial derivatives were obtained by O.Alyphanov(1973), L.Kozdoba, P.Krukovsky (1982), J.Bek, B.Blakuell and C.Sent-Kler (1989). The problems with approximate solution of incorrect problems set out in many works such as in a work of V.Ivanov, V.Vasin, V.Tanana (1978), A.Tyhanov, V.Arsenin (1986). The theoretical basics of methods to solve inverse problems and their practical application were studied in a works of A.Alekseeva, B.Mihailenko (1977), S. Kabanikhin, M. Bektemesov, D. Nechaev (2003). Methods of identifying the thermo physical properties of materials and products are studied in a works of B.Rysbaiuly, T.Akyshev, A.Ismailov, G.Mahambetova, A.Baimankulov, Z.Byrtaeva (2008-2010).

The universal device for determining the coefficient of heat transfer does not exist. It is determined by the empirical formulas, and through the establishment of facilities for the experimental determination. In order to define the coefficient of heat transfer, the average temperature of the surrounding is required, where dynamics of changes in temperature and air flow are not taken into account. The methods of predicting properties have not developed properly yet, and therefore, the main source of information remains experiment. The experimental determination of thermo physical characteristics of materials accompanied with some side effects such as heat leakage through the ends, convection, radiation, fluctuation of the temperature at the boundary of the solid and gas (liquid). During the heating procedure of investigated moist materials, redistribution of humidity will occur which will distort experimental data.

The installation of temperature detectors (sensors) is hold inside the body which is associated with some inconvenience due to the location of the thermocouples in the centre. This violates the integrity of the sample, which has a significant impact on the picture of the temperature field in the sample. Besides, there is required to maintain small geometric dimensions of investigated samples. However the sample of heterogeneous and composite materials, minerals and rocks cannot be in small dimensions. If the more complicated heat transfer will occur at the boundary of the body then such problems will be more difficult to solve both theoretically and practically.

The most appropriate way of determining the thermo physical characteristics of materials is non-destructive method based on the measurement of the temperature on the surface without violation of the integrity of the sample. Therefore, the elaboration of new methods of determining thermo physical properties of a product, materials, soil and ground are actual task.

In this work, the method of determining the coefficient of heat capacity and heat transfer of materials are being elaborated with a data from the surface. The proposed method allows to determine the coefficient of heat transfer and heat capacity during the single experiment without destruction of the structure of the material.

THE SOLUTION OF THE PROBLEM

i. The solution of the problem on the differential level

Let Oz axis to direct upwards, $z = H$ indicates the Earth surface. In the area of $Q = (0, H) \times (0, T)$, the distribution of heat is considered

$$\gamma_0 c \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial \theta}{\partial z}\right), \quad 0 < z < H, \quad 0 \le t \le T,$$

$$\theta\big|_{z=0} = T_1, \quad \lambda_n \frac{\partial \theta}{\partial z}\bigg|_{z=H} = -\alpha\left(\theta\big|_{z=H} - T_b(t)\right), \quad \theta\big|_{t=0} = \theta_0(z), \; 0 \le z \le H$$

$$\left[\lambda_n \frac{\partial \theta}{\partial z}\right]_{z=h_k(t)} = 0, \quad [\theta]_{z=h_k(t)} = 0 \; .$$

Where $[f]_{z=h(t)} = f(h(t)+0,t) - f(h(t)-0,t)$ is a leap of function at the point $z = h(t)$. Here k are a number of boundaries of a transition from one layer to another (gap). There is also given an additional condition

$$\theta(H, t, \alpha) = T_q(t) .$$

The coefficient of heat transfer is determined from the monotony of the functional

$$J(\alpha) = \int_0^T \left(\theta\big|_{z=H} - T_q(t)\right)^2 dt .$$

During the calculation conjugate problem was obtained:

$$\gamma_0 c \frac{\partial \psi}{\partial t} + \frac{\partial}{\partial z}\left(\lambda \frac{\partial \psi}{\partial z}\right) = 0,$$

$$\psi(z,T) = 0, \; \psi(0,t) = 0, \; \lambda_n \frac{\partial \psi}{\partial z}\bigg|_{z=H} + \alpha \psi^n\big|_{z=H} = -2\left(\theta^n\big|_{z=H} - T_g(t)\right),$$

$$\left[\lambda_n \frac{\partial \psi}{\partial z}\right]_{z=h_k(t)} = 0, \quad [\psi]_{z=h_k(t)} = 0 .$$

The initial approximation coefficient of heat transfer α_n is given and the next value is defined from the formula

$$\alpha_{n+1} = \alpha_n - \beta_n \int_0^T \left(\theta(H, t, \alpha_n) - T_q(t)\right)\psi(H, t, \alpha_n) dt .$$

ii. Difference scheme

Segment $(0,H)$ is divided into N equal sections with step $\Delta z = H/N$; and segment $(0,T)$ is divided into m equal section with step $\Delta t = T/m$. The net analogue of function $\theta(z_i,t_j)$ is denoted by Y_i^j, and then the net analogue $\theta(z_i,t_j+\Delta t)$ has a form Y_i^{j+1}. In this case, the area of $Q=(0,H)\times(0,T)$ transfers to the net

$$Q_N^m=\{z_i=i\cdot\Delta z;\ \ i=0,1,2,\dots,N;\ \ t_j=j\cdot\Delta t,\ \ j=0,1,2,\dots,m\}.$$

Let's move to the difference problem. In order to do this in the discrete area of Q_N^m is studied system

$$\gamma_0 c\frac{Y_i^{j+1}-Y_i^j}{\Delta t}=\frac{1}{\Delta z}\left(\lambda_{i+1}\frac{Y_{i+1}^{j+1}-Y_i^{j+1}}{\Delta z}-\lambda_i\frac{Y_i^{j+1}-Y_{i-1}^{j+1}}{\Delta z}\right), \tag{1}$$

$$Y_0^{j+1}=0,\ \lambda_N\frac{Y_N^{j+1}-Y_{N-1}^{j+1}}{\Delta z}=-\tilde{\alpha}_n\left(Y_N^{j+1}-T_b^{j+1}\right),\quad Y_i^0=\theta_0(z_i). \tag{2}$$

Here $\tilde{\alpha}_0=\alpha_0$ initial approximation coefficient of heat transfer. By using the temperature of the soil on the surface $T_q(t)$ the coefficient of heat transfer of ground to the surrounding is determined. During the theoretical reasoning the conjugate problem was obtained

$$\gamma_0 cU_{\bar{t}}+\left(\lambda U_z^j\right)_{\bar{z}}=0,\quad i=1,2,\dots,N-1;\ \ \mathrm{j}=m-1,m-2,\dots,1; \tag{3}$$

$$U_i^m=0,\ U_0^j=0,\ \lambda_{N,n}^j U_{N,\bar{z}}^j+\alpha U_N^j=-2(Y_N^{j+1}-T_q^{j+1}) \tag{4}$$

The value of approximation coefficient of heat transfer is determined from the monotony of the functional

$$I(\tilde{\alpha})=\sum_{j=1}^{m-1}\left(Y_N^{j+1}-T_q^{j+1}\right)^2\Delta t\ .$$

The next value of the coefficient of the heat transfer is defined by the formula

$$\tilde{\alpha}_{n+1}=\tilde{\alpha}_n-\tilde{\beta}_n\sum_{j=0}^{m-1}\left(Y_N^{j+1}-T_b^{j+1}\right)U_N^j\Delta t\ .$$

iii. Theoretical results

Lemma 1. If $\theta_0(z)\in L_2(0,H),\ T_b(t)\in L_2(0,T),$ then to solve the problem (1)-(2) the evaluation

$$\gamma_0\sum_i\left(cY_i^{j+1}\right)^2\Delta z+2\sum_{i,j}\lambda_{i,n}\left(Y_{i,\bar{z}}^j\right)^2\Delta z\Delta t+\tilde{\alpha}_n\sum_j\left(Y_N^{j+1}\right)^2\Delta t\le C_1\left(1+\tilde{\alpha}_n\right)$$ is appropriate.

Lemma 2. If $\theta_0(z)\in L_2(0,H),\ T_b(t),T_q(t)\in L_2(0,T),$ then to solve the system (3)-(4) the evaluation

$$\gamma_0\sum_i c_i^j U^2\Delta z+2\sum_{i,j}\lambda_{i,n}^j\left(U_{\bar{z}}^j\right)^2\Delta z\Delta t+\tilde{\alpha}_n\sum_j\left(U_N^j\right)^2\Delta t\le C_2\frac{1+\tilde{\alpha}_n}{\tilde{\alpha}_n^2}$$ is necessary.

Theory 1. If the lemma 1 and 2 are appropriate then by assuming

$$\tilde{\beta}_n \frac{1+\tilde{\alpha}_n}{\tilde{\alpha}_n \sqrt{\tilde{\alpha}_n}} = \frac{\beta}{n^k}, \text{ k} > 1$$

and managing parameter β it is always possible to obtain the inequality

$$0 < C_3 \le \tilde{\alpha}_n \le C_4 < \infty, n = 1,2,3,...$$

Theory 2. If the lemma 1, 2 and theory 1, and $B_n = \sum_{j=0}^{m-1} \left(Y_N^{j+1} - T_b^{j+1} \right) U_N^j \Delta t \neq 0$ are appropriate then by choosing the value of β, it is possible to obtain the inequality
$I(\tilde{\alpha}_{n+1}) < I(\tilde{\alpha}_n), \text{ n} = 0,1,2,...$

Theory 3. If the lemma 1, 2 and theory 1 are appropriate then there is exist an equality
$\lim_{\Delta t, \Delta z \to 0} \tilde{\alpha}_n = \alpha_n$.
The similar (analogous) result is obtained also for the coefficient of a heat capacity for the multi-layered ground.

THE NUMERICAL EXPERIMENTS

The object of the study was cut open development "Ekibastuzsky." To verify the correctness of the theoretical findings and the possibility of creating an instrument for determining the heat transfer coefficient and heat capacity, the experimental and numerical calculations were conducted for the three-layered ground (picture 1): 1-layer: silica sand; 2-layer: rocky ground with a mixture of sand; 3-layer: moist soil.

The temperature of the ground was measured by using the instrument Explorer GLX. The thicknesses of each layer are 100 cm, 100 cm and 500 cm respectively. The properties of a moist ground, stony ground and quartz sand are determined with the instrument IT-c-400 и IT- λ -400:

Table 1- numerical value of the measured thermo physical properties

The name of the material(substance)	γ, kg/m³	λ, watt/(m×degree)	C, kJ/(kg×degree)
Quartz sand	1380	0.48	0.2224
Rocky ground	1540	1.6	0.293846
Moist soil	1120	0.553	0.21128
Coal	984	0.193	0.272

The experiment was conducted for 3.5 hours by measuring the temperature of the air and surface of the soil. We studied dynamics of aspirations of the approximate values of the soil temperature and the coefficient of heat transfer to the real value in the process of iteration.

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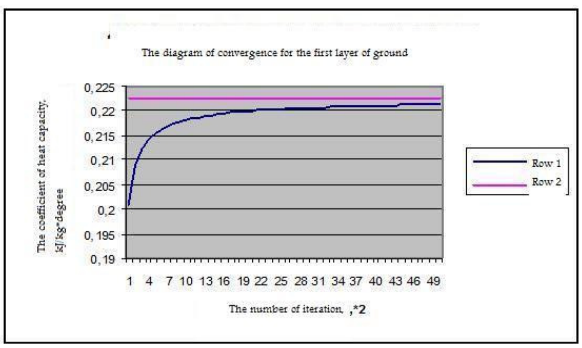
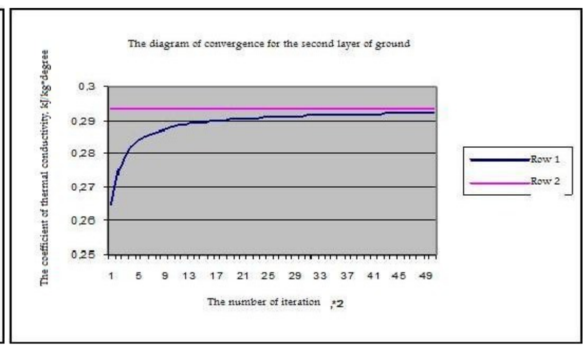
Picture 1-overburden stripping section of the field “Ekibastuzsky”

a. Determining the coefficient of heat capacity

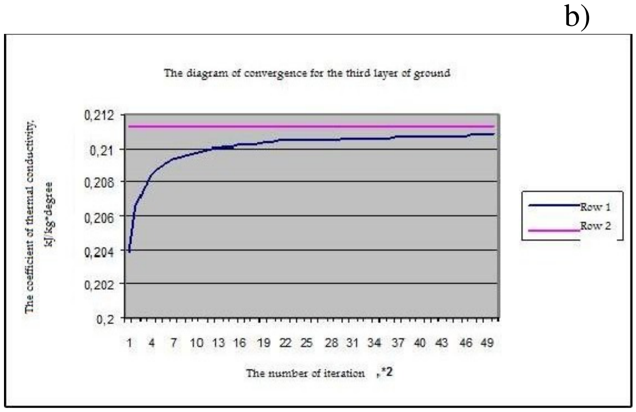
By using the table 1 and developed software package, the numerical calculations were conducted. This enables to check the convergence of the iterative scheme which is used to define the coefficient of heat capacity for every homogeneous layer of rocks. The optimal value of control parameters is set during the process of calculation each layer of rock. This enables to achieve the best convergence of iterative process.

The results of calculated experiments are presented as graphs and shown in the picture 2.





a) b)



c)

Picture 2-The diagrams of the convergence of calculated value of coefficient of heat capacity for different layer of ground in the area “Ekibastuzsky” to the measured (row 1 - the calculated values of heat capacity, row 2 - the measured values of heat capacity)

b. The calculation of heat transfer coefficient of a ground in the different areas of “Ekibastuzsky”

The empirical formula $\alpha = 11{,}4 + 7\sqrt{\omega}$ is given mostly in reference books and special literatures for the calculation of heat transfer coefficient. Here ω is a speed of the wind in m/s. Besides, the heat transfer coefficient of a ground depends on many parameters of a ground and environment. Therefore, the constants in $\alpha = 11{,}4 + 7\sqrt{\omega}$ should be clarified in each case. Based on this in the present study, we set out to determine the heat transfer coefficient of the section "Ekibastuzsky." For the heat transfer coefficient of a ground to the environment the next relation is considered

$$\alpha = E + F\sqrt{\omega}. \qquad (5)$$

Where E and F are undefined constants. With the interval of 5 min for the certain period of time, the temperature of the surroundings and ground was measured. The value of E and F in the formula 5 were determined by using developed program. As the initial data was taken:

- The thickness of each layer “Ekibastuzsky”;
-Thermal physical characteristics of each layer "Ekibastuzsky" (coefficient of specific heat, thermal conductivity and specific weight of soil);
- Air temperature and ground temperature at the surface.

The area “Ekibastuzsky” was divided into three sections A, B and C due to the thickness of the ground. The section A consists of 4 layers: moist ground-rocky ground-quartz sand-coal; the section B includes 2 layers: quartz sand-coal; and the section C comprises of only one layer-coal (picture 2-3).

Picture 3- “Ekibastuzsky” (view from above).

Table 2- the scheme of splitting area "Ekibastuzsky" into sections

Sections	Location	Sections	Location
A1	North side	B2	South side 12 m below
B1	North side 12 m below	A2	South side
C1	The bottom of the area 23 m below		

The numerical calculation with input data was performed in the site "Ekibastuzsky". The input data for each layer are: thickness of each layer, the thermo physical properties of each layer, the temperature of air and ground on the Earth surface, temperature of constant layer, initial temperature distribution in the ground, initial and final time, the interval of measurement of air and ground $dt = 1/12$ hours, step by spatial variable $dz = 0.001$ meter.

The picture 4-7 shows comparative graphs of measured and calculated temperature of the ground on the surface. To assess the accuracy, these formulas were used.

$Ma = \sum_{j=1}^{m} \frac{\Delta_j}{m}$ - an average value of uncertainty (error), $\sigma = \sqrt{\sum_{j=1}^{m} \frac{(\Delta_j - Ma)^2}{m}}$ is an average quadratic deviation. Here $\Delta_j = \left| T_q(t_j) - Y_N^j \right|$, $j = 1,2,...,m$.

Table 3.

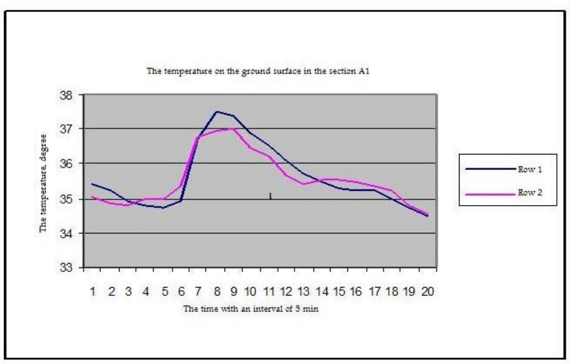
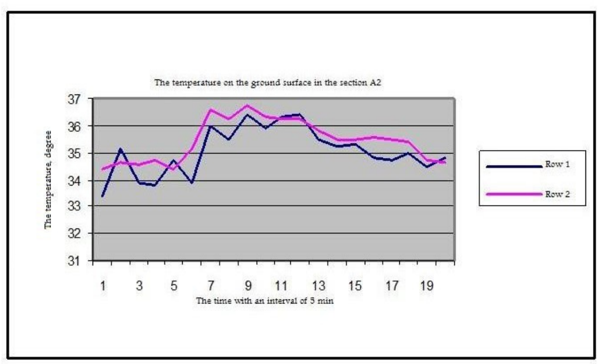
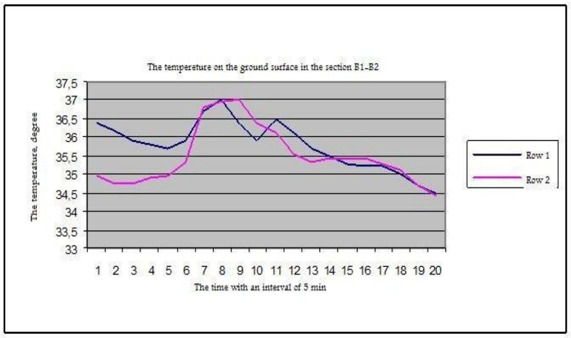
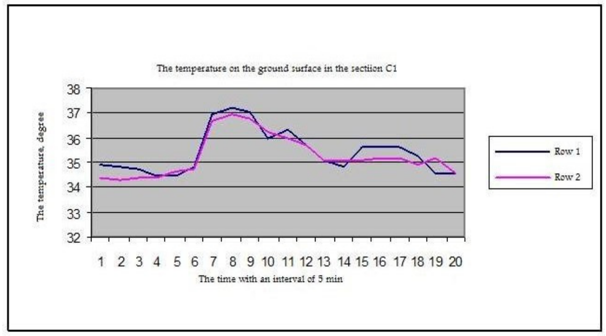
Section A1	Section A2
	
Picture 4- The temperature change on the ground surface (row 1- measured value, row 2-calculated value)	Picture 5- The temperature change on the ground surface (row 1- measured value, row 2-calculated value)
$\alpha = 10{,}8 + 3{,}36\sqrt{\omega}$	$\alpha = 11{,}27 + 3{,}37\sqrt{\omega}$
$Ma = 0{,}2682; \sigma = 0{,}1559$	$Ma = 0{,}4981; \sigma = 0{,}3185$

Table 4.

<table>
<tr><th>Section B1-B2</th><th>Section C1</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Picture 7- The temperature change on the ground surface (row 1- measured value, row 2-calculated value).</td><td>Picture 8- The temperature change on the ground surface (row 1- measured value, row 2-calculated value).</td></tr>
<tr><td>$\alpha = 7{,}23 + 2{,}61\sqrt{\omega}$</td><td>$\alpha = 6{,}82 + 2{,}55\sqrt{\omega}$</td></tr>
<tr><td>$Ma = 0{,}4977; \sigma = 0{,}4719$</td><td>$Ma = 0{,}2871; \sigma = 0{,}1695$</td></tr>
</table>

CONCLUSION

The iterative scheme for the calculation of heat transfer and heat capacity coefficients of multilayer soil is proposed. We prove the boundedness of the approximate value of the heat capacity and heat transfer coefficients, the convergence of iterative schemes. Example of the cut open development "Ekibastuzsky" shows that the value of the heat transfer coefficient is strongly dependent on the amount of soil thickness and thermophysical characteristics of soil layers. In the depth of the cut, values of the heat transfer coefficient decreases. The obtained values of coefficient E are similar to the value of standard formula $\alpha = 11{,}4 + 7\sqrt{\omega}$. The coefficient F has a significant difference at wind speed.

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