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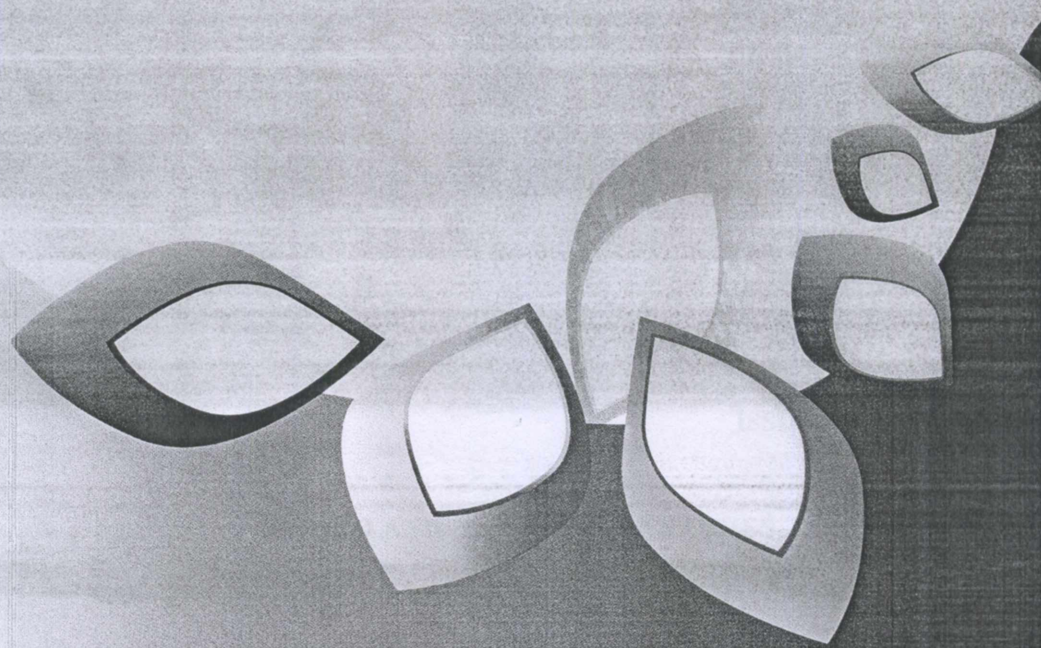

MICRO AND NANO TECHNOLOGIES

SPACE TECHNOLOGIES AND PLANETARY SCIENCE

18th INTERNATIONAL MULTIDISCIPLINARY SCIENTIFIC GEOCONFERENCE

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THE NONLLINEAR MATHEMATICAL 2D MODEL FOR THE ANALYSIS OF TEMPERATURE REGIMES IN THERMOSENSITIVE LAYERED MEDIUM WITH INCLUSIONS

Prof. Dr. Vasyl Havrysh[1]

Assoc. Prof. Dr. Roman Kochan[2,3]

PhD Lubov Kolyasa[4]

PhD Vasyl Loik[5]

Assoc. Prof. Dr Eng. Marcin Kubica[2]

[1] Software Department, Lviv Polytechnic National University, **Ukraine**

[2] Department of Computer Science and Automatics, University of Bielsko-Biala, **Poland**

[3] Department of Specialized Computer Systems, Lviv Polytechnic National University, **Ukraine**

[4] Department of Mathematics, Lviv Polytechnic National University, **Ukraine**

[5] Department of Fire Tactic and Rescue Works, Lviv State University of Life Safety, **Ukraine**

ABSTRACT

The aim of the paper is determination of the temperature field which is caused by a heat flux in a thermosensitive (thermophysical parameters depending on temperature) layered medium which contains a foreign inclusion. The heat flux is concentrated at one of the boundary surfaces of the medium, the other boundary surface of which is thermally insulated. There exists ideal heat contact at the surfaces of the conjugated layers. In order to determine temperature regimes in such a medium, a nonlinear equation of heat conduction with nonlinear boundary conditions is used. In order to solve the nonlinear boundary value problem of heat conduction, we introduce a linearizing function which enables us to obtain a partially linearized differential equation and linear boundary conditions to determine this function. After the piecewise-linear approximation of temperature with respect to spatial coordinates is carry out, a linear differential equation with discontinuous coefficients in the linearizing function is obtained. An analytical-numerical solution of the obtained linear boundary value problem is found with the use of Fourier integral transformation which determines the linearizing function and enables us to obtain calculation formulae for calculation of temperature. Let us consider a linear temperature dependence of the coefficient of heat conductivity of the material for a two-layer medium with an inclusion, and let us make a comparative numerical analysis of the distribution of temperature for a linear (coefficient of heat conductivity of the materials of the layers is a constant quantity) and a nonlinear one (coefficient of heat conductivity of the materials of the layers is a linear variable with respect to temperature) models (materials of the layers are U12 and 08 steels). The temperature field for a layer with a through inclusion (material of the layer is BK94–I ceramics, material of the inclusion is silver) have been calculated and analyzed.

Keywords: temperature, thermal conduction, heat-sensitive medium, inclusion

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INTRODUCTION

It is considered that the average temperature of the Earth's crust is equal to 15°C. Surface temperature variations can penetrate inside the earth, but to a limited depth. Daily variations vanish at a depth of 1–2 meters, and annual (seasonal) variations at a depth of 10–40 meters (with the exception of regions of eternal frost). The depth at which seasonal variations of temperature vanish is called the neutral level. Experimental investigations indicate that below the neutral level the temperature field of the Earth's crust practically does not vary with time, but just increase with the increase in the depth, this confirms the presence of heat flow from the center of the Earth to its surface. The Earth's crust consists of different kinds of layers, in particular, one of them can be a rock-bed. The geothermal (natural rock bed) temperature at a certain depth is determined according to the following relationship:

$$t_{nn} = t_0 + \Gamma_t y,$$

where t_0 is the average temperature of the neutral layer (in the territory of Ukraine $t_0 \approx 289\ K$); y is depth which is measured from the neutral level to the place of the rock-bed location; $\Gamma_t = \dfrac{dt}{dy}$ is the geothermal gradient. In practical investigations, for Ukraine the value of the geometric gradient is chosen to be equal to $2{,}7 \cdot 10^{-2}$ K/m. But numerous measurements indicate that its values change at the depths where oil or gas beds are located, which causes the change in the temperature of the bed; and this, in its turn causes the change in viscosity of fluids, of capillary forces, of rheological properties of fluids, of interphase exchange, etc. Therefore, in order to increase the current debits and in order to increase the oil extraction (especially from beds of oil of high viscosity) the temperature is to be increased by means of heat generation or by means of injection of hot heat agents. In order to determine the power of heat source, it is necessary to know the distribution of the temperature t with respect to the depth y; this enable us to obtain the value of the geothermic gradient Γ_t for different values of the depth y within a bed.

In the paper [1], the external asymptotic expansion of the solution of the non-stationary problem of heat conduction for layered anisotropic nonhomogeneous plates at face surfaces of which second kind boundary conditions are set has been carry out. The obtained 2D equations with the help of which we solve the problem have been analyzed. Asymptotic properties of the solutions of the problem have been investigated. The evaluation of accuracy with which the temperature in a plate beyond the boundary layer is considered as piece-wise linearly or piece-wise quadratically distributed with respect to the thickness of the layer structure has been obtained. Physical substantiation of some peculiarities of asymptotic expansion of temperature have been presented.

Heat transfer in a layered plate with different transparency components, which were joint by a thin inter layer under the condition of heat irradiation from a partially transparent layer has been investigated. Having introduced an effective coefficient of reflection at the contact surface, approximated relationship for determination of the field of radiation in the main partially transparent layer have been obtained. The nonlinear boundary value problem of heat transfer has been solved by means of finite-differences method with the application of the procedure of quasi linearization [2].

Some investigations of temperature fields for st
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under linear dependence of the coefficient o
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RESEARCH OBJECT AND ITS MATHEMA

An isotropic layered infinite plate of 2δ thickn
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and thermal (thermal conductivity coefficient)
rectangular coordinate system (x, y, z) with th
surfaces (Fig. 1) is considered. The plate includes
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is heated by a concentrated heat flow of the surf
of layers $K_j = \{(x, y_j, z): |x| < \infty, |z| \le \delta\} (j = \overline{1, n}$
$K_\pm = \{(\pm h, y, z):\ 0 \le y \le y_n, |z| \le \delta\}$ there

$t_j = t_{j+1},\quad \lambda_j(t)\dfrac{\partial t_j}{\partial y} = \lambda_{j+1}(t)\dfrac{\partial t_{j+1}}{\partial y}$ for

$\lambda_0(t)\dfrac{\partial t_0}{\partial x} = \lambda_j(t)\dfrac{\partial t_j}{\partial x}\ (j = \overline{1,n})$ to $|x| = h$ (0 – for i

and the boundary surface $K_n = \{(x, y_n, z): K$,
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solving the nonlinear equation of heat conduction

$$\frac{\partial}{\partial x}\left[\lambda(x,y,t)\frac{\partial t}{\partial x}\right] + \frac{\partial}{\partial y}\left[\lambda(\right.$$

with the boundary condition

$$t\Big|_{|x|\to\infty} = 0, \frac{\partial t}{\partial y}\Big|_{y=y_n} = 0, \quad \lambda_0(t)\frac{\partial t}{\partial y}\Big|_{y=0} = -q$$

where $\lambda(x,y,t) = \sum_{j=1}^{n} \{\lambda_j(t) + [\lambda_0(t) - \lambda_j(t)]S_-($
heat conductivity of the heterogeneous heat-sens
conductivity coefficient of the material of the
respectively; $y_0 = 0$; $N(y, y_{j-1}) = S_+(y - y_{j-1}) - S$

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the procedure of quasi linearization [2].

Some investigations of temperature fields for structural thermosensitive elements of a piece-wise homogeneous structure had been carried out before [3]. The boundary value nonlinear problem of heat conduction has been formulated below. A technique of its linearization and calculation formulae for determination of the temperature field in the thermosensitive layered medium with a through inclusion, which is heated by a concentrated at one of its surfaces heat flow have been presented. A numerical analysis under linear dependence of the coefficient of thermoconductivity of materials of structures on temperature have been carried out.

RESEARCH OBJECT AND ITS MATHEMATICAL MODEL

An isotropic layered infinite plate of 2δ thickness with the thermally insulated face surface $|z| = \delta$ which consists of n heterogeneous layers of differing geometric (width) and thermal (thermal conductivity coefficient) parameters referred to the Cartesian rectangular coordinate system (x, y, z) with the beginning of one of its boundary surfaces (Fig. 1) is considered. The plate includes a through inclusion and in the domain $\Omega_0 = \{(x,0,z): |x| \le h, |z| \le \delta\}$ of its boundary surface $K_0 = \{(x,0,z): |x| < \infty, |z| \le \delta\}$ it is heated by a concentrated heat flow of the surface density $q_0 = const$. At the surfaces of layers $K_j = \{(x, y_j, z): |x| < \infty, |z| \le \delta\} (j = \overline{1, n-1})$ and at the surface of the inclusion $K_\pm = \{(\pm h, y, z):\ 0 \le y \le y_n, |z| \le \delta\}$ there is perfect thermal contact

$$t_j = t_{j+1},\quad \lambda_j(t)\frac{\partial t_j}{\partial y} = \lambda_{j+1}(t)\frac{\partial t_{j+1}}{\partial y} \quad \text{for} \quad y = y_j \quad (j = \overline{1, n-1}); \quad t_0 = t_j,$$

$\lambda_0(t)\dfrac{\partial t_0}{\partial x} = \lambda_j(t)\dfrac{\partial t_j}{\partial x}$ $(j = \overline{1, n})$ to $|x| = h$ (0 – for inclusion, j – for the j-th layer of plate), and the boundary surface $K_n = \{(x, y_n, z): K_n = |x| < \infty, |z| \le \delta\}$ plate is thermally insulated. In the given structure, it is necessary to determine the distribution of temperature $t(x, y)$ with respect to the coordinates of space which is obtained from solving the nonlinear equation of heat conduction

$$\frac{\partial}{\partial x}\left[\lambda(x,y,t)\frac{\partial t}{\partial x}\right] + \frac{\partial}{\partial y}\left[\lambda(x,y,t)\frac{\partial t}{\partial y}\right] = 0 \tag{1}$$

with the boundary condition

$$t\Big|_{|x|\to\infty} = 0,\ \frac{\partial t}{\partial y}\Big|_{y=y_n} = 0,\quad \lambda_0(t)\frac{\partial t}{\partial y}\Big|_{y=0} = -q_0 S_-(h - |x|), \tag{2}$$

where $\lambda(x,y,t) = \sum_{j=1}^{n} \{\lambda_j(t) + [\lambda_0(t) - \lambda_j(t)] S_-(h - |x|)\} N(y, y_{j-1})$ is the coefficient of heat conductivity of the heterogeneous heat-sensitive plate; $\lambda_j(t)$, $\lambda_0(t)$ are the thermal conductivity coefficient of the material of the j-layer plate and of the inclusion, respectively; $y_0 = 0$; $N(y, y_{j-1}) = S_+(y - y_{j-1}) - S_+(y - y_j)$;

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$$S_{\pm}(\zeta)=\begin{cases}1, & \zeta>0\\ 0,5\mp 0,5, & \zeta=0\\ 0, & \zeta<0\end{cases}$$ is the asymmetric unit functions.

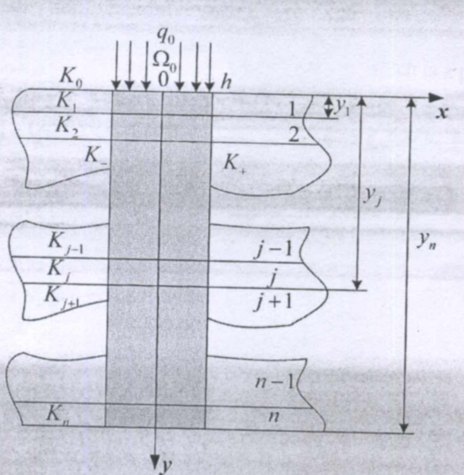

Figure 1. The section of isotropic multilayered infinite plate with foreign through-plane inclusion $z=0$.

Let us introduce the linearizing function

$$\begin{aligned}\vartheta(x,y)=\sum_{j=1}^{n}\{N(y,y_{j-1})\int_{0}^{t(x,y)}\lambda_j(\zeta)d\zeta+S_-(x+h)\,[N(y,y_{j-1})\int_{t(-h,y)}^{t(x,y)}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta\\ -S_+(y-y_{j-1})\int_{t(-h,y_{j-1})}^{t(x,y_{j-1})}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta\,S_+(y-y_{j-1})+S_+(y-y_j)\int_{t(-h,y_j)}^{t(x,y_j)}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta\,]\\ -S_+(x-h)\,[N(y,y_{j-1})\int_{t(h,y)}^{t(x,y)}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta-S_+(y-y_{j-1})\int_{t(h,y_{j-1})}^{t(x,y_{j-1})}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta+\\ +S_+(y-y_j)\int_{t(h,y_j)}^{t(x,y_j)}(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta\,]-S_+(y-y_{j-1})\int_{0}^{t(x,y_{j-1})}\lambda_j(\zeta)d\zeta+S_+(y-y_j)\int_{0}^{t(x,y_j)}\lambda_j(\zeta)d\zeta\,\}\end{aligned}\qquad(3)$$

Taking into account the expressions (3) the original equation (1) and the boundary conditions (2) takes the following form:

$$\frac{\partial^2\vartheta}{\partial y^2}-\frac{\partial}{\partial x}[F_1(x,y)]+\frac{\partial}{\partial y}[F_2(x,y)]=0.\qquad(4)$$

$$\vartheta\Big|_{|x|\to\infty}=0,\ \frac{\partial\vartheta}{\partial y}\Big|_{y=y_n}=0,\qquad \frac{\partial\vartheta}{\partial y}\Big|_{y=0}=-\ldots$$

With the use of piece-wise linear approximation o… with application of Fourier transformation with resp… an analytical-numerical solution of the problem (4), (…

A PARTIAL EXAMPLE AND ANALYSIS OF T…

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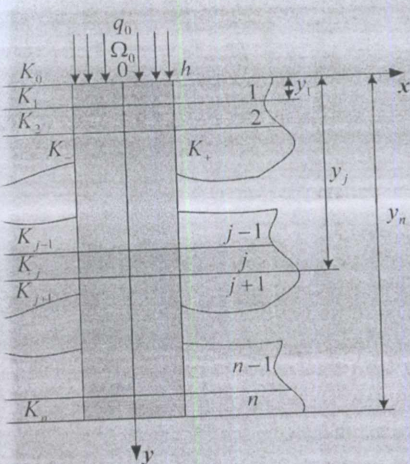

ction of isotropic multilayered infinite plate with foreign through-plane inclusion $z = 0$.

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$$\int_0^{t(x,y)} \lambda_j(\zeta)d\zeta + S_-(x+h)[N(y,y_{j-1})\int_{t(-h,y)}^{t(x,y)} (\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta$$

$$-\lambda_j(\zeta))d\zeta\, S_+(y-y_{j-1}) + S_+(y-y_j)\int_{t(-h,y_j)}^{t(x,y_j)} (\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta\,]$$

$$(\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta - S_+(y-y_{j-1})\int_{t(h,y_{j-1})}^{t(x,y_{j-1})} (\lambda_0(\zeta)-\lambda_j(\zeta))d\zeta + \quad (3)$$

$$_j(\zeta))d\zeta\,] - S_+(y-y_{j-1})\int_0^{t(x,y_{j-1})} \lambda_j(\zeta)d\zeta + S_+(y-y_j)\int_0^{t(x,y_j)} \lambda_j(\zeta)d\zeta$$

e expressions (3) the original equation (1) and the takes the following form:

$$\frac{\partial^2 \vartheta}{\partial y^2} - \frac{\partial}{\partial x}[F_1(x,y)] + \frac{\partial}{\partial y}[F_2(x,y)] = 0. \quad (4)$$

$$\vartheta\Big|_{|x|\to\infty} = 0,\ \frac{\partial \vartheta}{\partial y}\Big|_{y=y_n} = 0,\qquad \frac{\partial \vartheta}{\partial y}\Big|_{y=0} = -q_0 S_-(h-|x|). \quad (5)$$

With the use of piece-wise linear approximation of the function $t(\pm h, y), t(x, y_j)$ and with application of Fourier transformation with respect to the coordinate x, we obtain an analytical-numerical solution of the problem (4), (5).

A PARTIAL EXAMPLE AND ANALYSIS OF THE RESULTS.

In order to solve many practical problems, the following dependence of thermal conductivity coefficient on the temperature is applied:

$$\lambda_s(t) = \lambda_s^0(1 - k_s t), \quad (6)$$

where λ_s^0, k_s is the reference and temperature coefficients of thermal conductivity of materials for an inclusion (s=0) and j-th layer of the plate (s=j), $j = \overline{1,n}$. Taking into account this dependence and expression (3) we shall obtain formulas for determining the temperature $t(x,y)$ for the two-layer plate (n=2) which fully describe the temperature field.

A numerical analysis of the dimensionless temperature $t^* = \lambda_0 t/(q_0 h)$ in the plate of $2l$ width with the through inclusion have been made for the following initial data: material of the the plate – BK94-I ceramics, inclusion material – silver, $n = 10$ is the number of subintervals partitions of the interval $]-l;l[$; $l/h = 1$. In the temperature range of $[20\ ^\circ C; 1230\ ^\circ C]$ the aforesaid materials are described by the following dependences of the coefficient of heat conductivity on temperature [4]:

$$\lambda_1(t) = 13{,}67\frac{\text{W}}{\text{Km}}(1 - 0{,}00064\frac{1}{\text{K}}t), \qquad \lambda_0(t) = 422{,}54\frac{\text{W}}{\text{Km}}(1 - 0{,}00031\frac{1}{\text{K}}t), \quad (7)$$

which is a partial case of ratio (6).

The dependence of dimensionless temperature t^* on the dimensionless coordinates $x^* = x/h$ and $y^* = y/h$ (see Fig.2) has been constructed. Let us notice that the temperature reaches its maximal value in the domain of concentrated heat flow.

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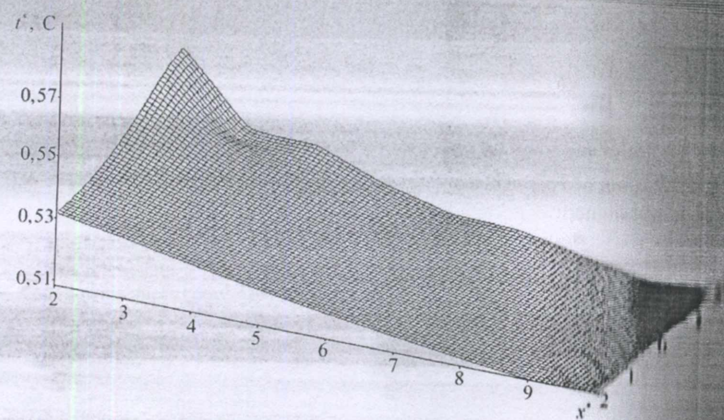

Figure 2. Dependence of dimensionless temperature t^* on dimensionless coordinates x^* and y^*.

The change of the dimensionless temperature t^* depending on the dimensionless coordinate y^* for $x^*=0$ (Fig. 3, a) and x^* for $y^*=0$ (Fig. 3, b) is illustrated Fig. 3. The behaviour of the curves indicates compliance of the mathematical model of real physical process, since at the surfaces $K_{\pm}$ ($|x|=1$) of the inclusion we observed the satisfaction of the conditions of ideal thermal contact (no temperature jump).

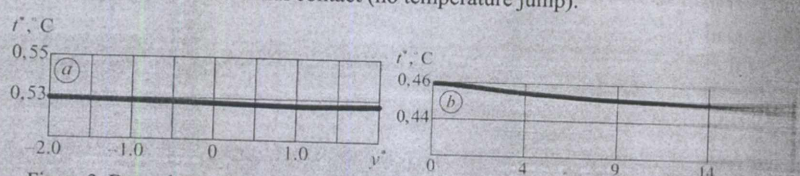

Figure 3. Dependence of dimensionless temperature t^* on dimensionless coordinates y^* for $x^*=0$ (a) and x^* for $y^*=0$ (b).

Let us consider a two-layered plate with uniformly distributed heat sources at the surfaces of layer interface (Fig. 4). Suppose that at the boundary surfaces of plate $y=y_1$, $y=y_2$, temperature is $t_1=0$°C, $t_2=700$°C, respectively. Material of the plate's layers is steel U12 and 08.

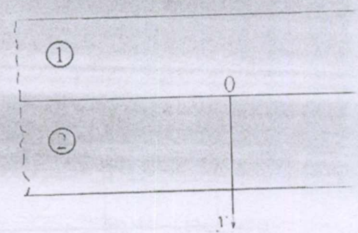

Figure 4. Two-layered p

In the temperature range of [0°C; 700°C] these materia
dependences of thermal conductivity coefficient on the

$$\lambda_1(t) = 47,5\frac{W}{Km}(1-0,00037\frac{1}{K}t), \qquad \lambda_2(t) = 64,5\frac{W}{K}$$

We performed numerical calculations of temperature
thermal conductivity coefficient of materials of layers
(W/(Km)) (Fig. 5, curve 1). The distribution of t
linearly variable thermal conductivity coefficient of
expressed by ratios (8)) is shown in Fig. 5 (curve 2); y

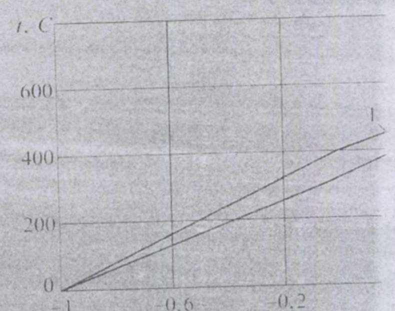

Figure 5. Dependence of temperature t on the y
linearly variable (curve 2) coefficient o
of materials of layers

Behavior of the curves indicates conformity of t
physical process because at the surfaces of layer int
how conditions for an ideal thermal contact are sat
The results obtained for the chosen materials
conductivity coefficient on the temperature differ
coefficient of thermal conductivity by 15 %.

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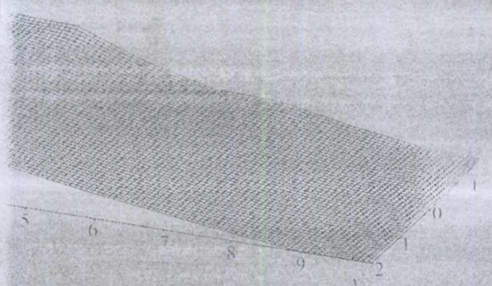
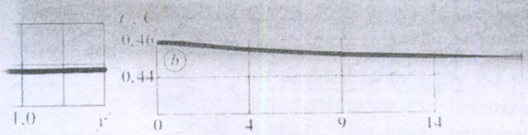


dimensionless temperature t^* on dimensionless coordinates x^* and y^*.

less temperature t^* depending on the dimensionless 3, *a*) and x^* for $y^*=0$ (Fig. 3, *b*) is illustrated Fig. 3. The es compliance of the mathematical model of real physical $X_\pm$ ($|x|=1$) of the inclusion we observed the satisfaction of contact (no temperature jump).



nsionless temperature t^* on dimensionless coordinates y^* for $x^*=0$ (*a*) and x^* for $y^*=0$ (*b*).

ed plate with uniformly distributed heat sources at the g. 4). Suppose that at the boundary surfaces of plate t_2=700ºC, respectively. Material of the plate's layers is

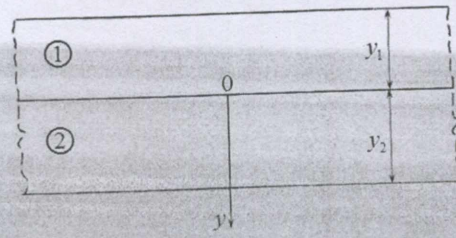


Figure 4. Two-layered plate.

In the temperature range of [0⁰C; 700⁰C] these materials are described by the following dependences of thermal conductivity coefficient on the temperature:

$$\lambda_1(t) = 47{,}5\frac{W}{Km}(1-0{,}00037\frac{1}{K}t), \qquad \lambda_2(t) = 64{,}5\frac{W}{Km}(1-0{,}00049\frac{1}{K}t). \tag{8}$$

We performed numerical calculations of temperature field for a linear model (constant thermal conductivity coefficient of materials of layers of the plate; λ_1=38.7W/(Km), λ_2= =48.7W/(Km)) (Fig. 5, curve 1). The distribution of temperature for a nonlinear model (linearly variable thermal conductivity coefficient of materials of layers of the plate, expressed by ratios (8)) is shown in Fig. 5 (curve 2); y_1=y_2=1 m.

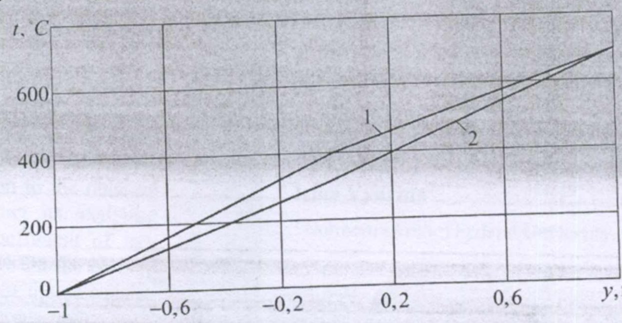


Figure 5. Dependence of temperature t on the y coordinate for a stable (curve 1) and linearly variable (curve 2) coefficient of thermal conductivity of materials of layers of the plate.

Behavior of the curves indicates conformity of the mathematical model with a real physical process because at the surfaces of layer interface of the plates (x=0) we observe how conditions for an ideal thermal contact are satisfied (temperature jump is missing). The results obtained for the chosen materials by a linear dependence of thermal conductivity coefficient on the temperature differ from the results obtained for a stable coefficient of thermal conductivity by 15 %.

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CONCLUSION

The introduce linearizing function has enabled us to partially linearize the given non-linear equation of heat conduction and to wholly linearize the boundary condition; and the suggested piece-wise linear approximation of temperature at boundary surfaces of the inclusion and of foreign layers has enabled us to fully linearize the differential equation. This enabled us to apply the Fourier integral transformation to the obtained linear problem concerning the linearizing function and to construct its analytical numerical solution. The linear temperature dependence of the coefficient of heat conductivity for materials of the inclusion and for the two-layer plate. On the basis of this, calculation formulae for calculating the values of temperature in the considered structure have been created. The obtained results for the chosen materials under linear dependence of the coefficient of heat conductivity on temperature differ by 7% from the results which have been obtained for constant coefficient of heat conductivity [3]. Their inconsiderable divergence is accounted for by the fact at the real values of the temperature coefficient of heat conductivity for the considered materials are low.

The scientific novelty consists in the fact that a linearizing function, with the help of which partial linearization of nonlinear boundary value problem of heat conduction is made, enabled us to obtain calculation formulae for determining the distribution of temperature in a piecewise homogeneous medium.

The practical value consists in the improvement of accuracy of calculation of temperature fields and in effectiveness of methods of investigation of thermosensitive piece-wise homogeneous media. The precision is achieved at the expanse of taking into account the piecewise homogeneous structure of the medium and that of the dependence of the coefficient of heat conductivity of the materials of the medium on temperature (nonlinear model).

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THE REACTOR SYSTEM FOR BIOSY CELLULOSE WITH DESIRED MICR

Assoc. prof. PhD. Ksenia Bolotova[1]

Irina Vydrina[1]

[1] Northern (Arctic) Federal University, **Russia**

ABSTRACT

The drip feed reactor system for continuous bio desired microfibril orientation is proposed. Native glucose media using symbiotic complex o Micromorphological characteristics of the bacter using SEM Sigma VP ZEISS scanning electron m the specimens is calculated by new method usin diffractometer).

The 28 cm-long bacterial cellulose specimen was during 12 days continuous cultivation. Internal bi observed. Globular microfibril structures were cellulose in the drip feed reactor system unli conditions. The diffraction patterns of bacterial cel and dynamic (the drip feed reactor system) condit basic crystalline compound of the specimens wa degree of bacterial cellulose from the reactor sys synthesized in static conditions this parameter w bacterial cellulose became less oriented because parts in comparison with structure of bacterial cell

Keywords: microfibril's orientation, bacteria crystallinity degree

INTRODUCTION

Natural symbiotic systems associated with biofil researchers as microbial mats. The research of importance for biosphere evolution, productional cycle. The mats (biofilms) microorganisms are in enzymes, biologically active substance, endo- an most popular exopolysaccharide, being of the microbiologic consortium is cellulose (bacter *Gluconacetobacter*, bacteria *Achromobacter, Alc Azotobacter, Gluconacetobacter, Pseudomonas,* base of microbial community (edificator) for the b

The traditional approaches for cellulosic materia different pulp and paper technologies. The qu semifinished products as well as chemical comp

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