ABSTRACTS

MASS TRANSFER IN THE GASEOUS PHASE IN THE CASE OF NONEQUIMOLAR TRANSER OF MATTER IN A FILM COLUMN

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UDC 66.048

The article analyzes the literature data on the effect of the concentration of an inert gas on the mass-transfer coefficient and treats the published data on evaporation in a film column. A system of differential equations of the process of simultaneous heat and mass transfer is given for the calculation.

It was established that the equation of nonequimolar mass transfer obtained from the Stefan–Boltzmann relations according to the film theory of mass transfer describes satisfactorily mass transfer in binary mixtures also in the case of turbulent gas flow in film columns. Consequently, for the conditions considered, this equation is obtained by solution of the time-averaged equations of motion, continuity, and diffusion. On this one can obtain the equation of nonequimolar transfer of matter in multicomponent mixtures, bearing in mind that in the case of insignificant velocities of mass transfer in comparison with the velocity of the medium the equations of motion are the same for binary and multicomponent mixtures, and one can describe diffusion in multicomponent mixtures by approximate linearized equations. For a slight change of concentration in the direction of transfer the article presents a derivation, using matrix transformations, of an equation which shows that the difference between the total quantity of the component being transferred and that quantity which is transferred by the total flow is determined by the usual equation of equimolar transfer. This permitted the use of the known approximate equation of equimolar mass transfer in multicomponent mixtures to write the equation of nonequimolar mass transfer in a general form

$$N_i - y_{i_{\mathrm{av}}} \mathrm{N}_{\mathrm{E}} = \sum_{j=1}^{n} \beta_{ij} (y_{if} y_j - y_i y_{jf}),$$

where N is the molar flow of matter; N_t is the total transverse flow of matter; y is the mole fraction; β_{ij} is the mass-transfer coefficient corresponding to the multicomponent mixture. Subscripts 1, 2, i, j denote the components or transformed functions; n denotes the number of components; av denotes the arithmetic mean; f denotes the interface.

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DETERMINATION OF THE CRITICAL ELECTROSTATIC FIELD STRENGTH FOR A FLOWING FILM OF LIQUID DIELECTRIC

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An increase of the heat-transfer coefficient during condensation of Freons in an electrostatic field upon reaching a certain value of field strength (about 2 kV/mm) was noted in [1, 2]. In this case visual observation revealed runoff of the condensate from the electrodes.

The article considers the flow of the film of a liquid dielectric on a flat plate in an electrostatic field in order to determine the effect of the physical parameters of the dielectric on the magnitude of the critical field strength at which separation of the dielectric from the surface occurs.

The critical field strength is determined from conditions of equality of the surface tension forces and electrostatic field during steady flow of the film.

In determining the forces it was assumed in the first approximation:

1) that the electrostatic field strength in the film and in the vapor differ insignificantly from the strength in the case of plane flow of a dielectric film;
2) that, for wave flow of the dielectric, $1 + y'^2 = 1$, which is valid in the case of a small curvature of the surface of the waves ($\lambda \gg h_0$).

In conformity with the assumptions made, the surface-bound charge density at the phase interface on the side of the liquid

$$\varkappa = E_0 \frac{\varepsilon_0 (\varepsilon_l - 1)}{\varepsilon_l}. \tag{1}$$

The density of the surface ponderomotive forces acting on these charges,

$$P_E = \varkappa E_0 \frac{\varepsilon_l + 1}{2\varepsilon_l} \tag{2}$$

or, using Eq. (1),

$$P_E = \frac{E_0^2 \varepsilon_0 (\varepsilon_l^2 - 1)}{2\varepsilon_l^2}. \tag{3}$$

With consideration of the assumptions made and [3] for a moving thin liquid film, the density of the surface tension forces can be determined for the wave crest

$$P_\sigma = -\alpha k^2 \sigma h_0. \tag{4}$$

The critical electrostatic field strength is determined from the condition $|P_E| \geq |P_\sigma|$:

$$E_{\mathrm{cr}} = k\varepsilon_l \sqrt{\frac{2\alpha\sigma h_0}{\varepsilon_0 (\varepsilon_l^2 - 1)}}. \tag{5}$$

In [4] the parameters of a steady wave flow k, α, and h_0 are determined from the condition of a minimum value of the potential energy and the presence of a harmonic character of the film flow.

The energy of the electrostatic field per unit volume is

$$T^E_{\mathrm{p.e.}} = \frac{E_0^2 \varepsilon_0}{2} \left[1 + \frac{h_0}{d} (\varepsilon_l - 1)\right]. \tag{6}$$

It is seen from Eq. (6) that with a decrease of the film thickness the potential energy of the electrostatic field, like the gravitational forces, decreases. Consequently, to a first approximation the parameters of a wave flow determined according to [3, 4] can be used in determining the critical field strength.

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Calculations by Eq. (5) with the use of the data of experimental studies [1, 2] gave the following values of the field strength at which separation of the film occurs: for Freon-113 [1] $E_{cr} = 1.4$ kV/mm; for Freon-11 [2] $E_{cr} = 1.6$ kV/mm.

NOTATION

E_0	is the strength of the electrostatic field created by free charges of the electrodes;
E_{cr}	is the critical electrostatic field strength;
$T_{p.e.}$	is the potential energy;
P_E	is the density of the surface ponderomotive forces;
P_σ	is the density of the surface tension forces;
d	is the distance between electrodes;
h	is the thickness of the liquid dielectric film;
h_0	is the average film thickness;
y	is the moving coordinate of the axis perpendicular to the surface of the plane wall;
k	is the wave number;
$\lambda = 2\pi/k$	is the wavelength;
α	is the coefficient determining the amplitude of the wave flow of the film;
σ	is the surface tension force;
$\varkappa$	is the surface-bound charge density of liquid dielectric at phase interface;
ε_l	is the dielectric constant;
ε_0	is the permittivity of free space.

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DETERMINATION OF HEAT INFLUXES THROUGH THE NECK OF A CRYOGENIC LIQUID CONTAINER

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UDC 536.22

Evaporation caused by heat influxes through the neck of a vessel of cryogenic liquid is analytically studied in the article. A calculation is conducted taking into account the temperature dependence of the heat-conduction coefficient of the material of the neck. The problem is solved with the following assumptions: 1) the coefficient of heat exchange of the wall of the neck with the gas is constant; 2) the physical properties of the gas do not depend on the temperature; 3) axial heat conduction through the gas is absent; 4) heat influxes to the neck through the container insulation are negligibly small.

With the assumptions made, the equations of heat conduction for the wall of the neck and of energy for the gas flow are converted to the form

$$\bar{Q}\frac{d\bar{Q}}{d\bar{T}} = \left(\frac{B}{A}\right)^2 \lambda(\bar{T})(\bar{T}+K-\bar{Q}), \tag{1}$$

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where

$$\overline{Q}=\frac{Q}{mc\,(T_0-T_{\mathrm{c}})};\ A=\frac{mcL}{s};\ K=\frac{r}{c\,(T_0-T_{\mathrm{c}})};$$

$$B=\left(\frac{\alpha pL^2}{s}\right)^{1/2};\ \overline{T}=\frac{T-T_{\mathrm{c}}}{T_0-T_{\mathrm{c}}}$$

(Q is the heat flux along the neck; T is the wall temperature; T_0 and T_c are the temperatures of the hot and cold ends of container neck; m is the evaporation of the liquid; C is the isobaric heat capacity of the gas; λ is the coefficient of heat conduction; s, p are the area and perimeter of the cross section of the neck wall; L is the neck; r is the latent heat of vaporization; α is the heat-exchange coefficient).

Equation (1) is solved numerically at a fixed value of the parameter B/A, as a result of which the dependence $\overline{Q}(\overline{T})$ is obtained. The variable A was computed from the values of $\overline{Q}(\overline{T})$

$$A=\int_0^1\frac{\lambda(\overline{T})\,d\overline{T}}{\overline{Q}}.$$

The dependence A = f(B) is obtained over the range $0 \le B \le 50$. The calculations were conducted on the Minsk-22 computer for liquid helium and hydrogen. The temperature of the hot end of the neck (T_0) was chosen to be equal to the temperature of the surrounding medium (300°K), of liquid nitrogen, and hydrogen (77.4 and 20.4°K, respectively). The neck material was Kh18N10T steel.

The results of the calculation are presented in the form of graphs of the dependence of the dimensionless evaporation $A/\overline{\lambda}$ on the dimensionless parameter $\beta = B\sqrt{\overline{\lambda}} = L\sqrt{\alpha p/s\overline{\lambda}}$ ($\overline{\lambda}$ is the mean integral heat-conduction coefficient). A comparison with the solution for $\lambda = \overline{\lambda} = \mathrm{const}$ is presented; it is shown that in this case the value $A/\overline{\lambda}$ is 2.5 times higher for liquid helium and 35% higher for liquid hydrogen at $T_0 = 300$°K.

THE EFFECT OF THE TEMPERATURE DEPENDENCE OF CONDUCTIVITY ON THE TEMPERATURE DISTRIBUTION, CURRENT, AND ELECTROMAGNETIC FIELD IN A PLANE LAYER

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UDC 538.56+536.212.2

The steady-state temperature and electromagnetic field in the plane layer $|z| \le 1$ on the cooled surfaces of which a constant temperature is specified, as well as a monochromatic tangential electrical field of amplitude e^0, is the solution of the following system of equations and boundary-value conditions:

$$t''=-\sigma|e|^2,\ e''=2i\nu^2\sigma e;\ t(1)=t'(0)=e'(0)=0,\ e(1)=1; \tag{1}$$

$j = \sigma e$ and $h = ie'$ determine e. Here z is a coordinate; t is the temperature; $\sigma = \sigma(t) = 1 - kt$ is the conductivity; **e**, **h**, and **j** are complex amplitudes of the electrical and magnetic fields and current densities referred, respectively, to the quantities a, $\sigma^0(ae^0)^2/2\lambda$, $\sigma^0 \equiv \sigma(0)$, e^0, $e^0/a\mu\omega$, $\sigma^0 e^0$; λ, μ, α, $2a$ are the thermal conductivity, magnetic permeability, temperature conductivity coefficient, and thickness of the plane layer; ω is the frequency; $\nu \equiv n/2 = a\sqrt{\sigma^0\mu\omega/2}$; $k = \sigma^0(ae^0)^2\alpha/2\lambda$; **e** is parallel to $\mathbf{e}^0$; **h** is orthogonal to $\mathbf{e}^0$ and parallel to the layer surfaces.

By seeking the solution in the form of a series $t = \sum\limits_{l=0} k^l t_l$, one obtains for the coefficients linear equations which can be integrated in quadratures. In particular, the first approximation assumes a familiar

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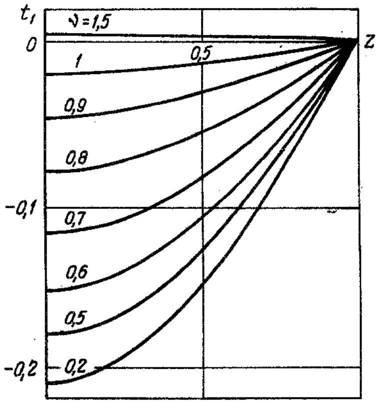

Fig. 1. The dependence of t_1 on z for various values of ν.

form

$$t_0=\frac{c_2(n)-c_2(nz)}{n^2c_1(n)},\quad e_0=j_0=\frac{\mathrm{ch}\,(1+i)\,\nu z}{\mathrm{ch}\,(1+i)\,\nu},\quad h_0=(i-1)\,\frac{\mathrm{sh}\,(1+i)\,\nu z}{\mathrm{ch}\,(1+i)\,\nu}\,; \tag{2}$$

for the first correction proportional to k one obtains

$$\begin{aligned}2n^4c_1^2(n)\,t_1={}&\left\{\frac{nc_2(n)-s_2(n)}{2c_1^2(n)}\,[s_2(2n)-2f_4(n)]-\frac{1}{5}\left[6\,\frac{f_3(n)}{c_1(n)}+7c_2(n)\right]+2c_2(n)\right\}[c_2(n)-c_2(nz)]\\&+\frac{1}{10}\,\{4\,[f_1(n)-f_1(nz)]+3\,[c_1(2n)-c_1(2nz)]\}-nc_2(n)\,[s_1(n)-zs_1(nz)];\end{aligned} \tag{3}$$

$$\begin{aligned}2n^2c_1^2(n)\,\mathrm{Re}\,e_1={}&[c_2(n)\,nz-s_2(nz)]\,f_{1432}^{-}+\frac{nc_2(n)-s_2(n)}{c_1(n)}\,\{f_3(n)\,f_{2143}^{-}-[f_1(n)+1]\,f_{2341}^{+}\}\\&+\frac{1}{5}\left\{\left[12\,\frac{f_1(n)+1}{c_1(n)}-c_1(n)+c_1(nz)\right]f_{1331}^{-}+3\,[c_2(n)-c_2(nz)]\,f_{1133}^{+}\right\},\end{aligned} \tag{4}$$

$$\begin{aligned}2n^2c_1^2(n)\,\mathrm{Im}\,e_1={}&-[c_2(n)\,nz-s_2(nz)]\,f_{1234}^{+}+\frac{nc_2(n)-s_2(n)}{c_1(n)}\,\{f_3(n)\,f_{2341}^{+}+[f_1(n)+1]\,f_{2143}^{-}\}\\&+\frac{1}{5}\left\{3\left[c_2(n)-c_2(nz)-4\,\frac{f_3(n)}{c_1(n)}\right]f_{1331}^{-}+[c_1(n)-c_1(nz)]\,f_{1133}^{+}\right\};\end{aligned} \tag{5}$$

$$j_1=e_1-e_0t_0=e_1-\frac{c_2(n)-c_2(nz)}{2\nu^2c_1^2(n)}\,(f_{1133}^{+}+i\,f_{1331}^{-}); \tag{6}$$

$$\begin{aligned}4nc_1^2(n)\,\mathrm{Re}\,h_1={}&2\left[c_2(n)\,nz-\frac{4}{5}\,s_2(nz)\right]f_{1133}^{+}+\frac{nc_2(n)-s_2(n)}{c_1(n)}\\&\times\{[f_1(n)+1]\,f_{2442}^{+}+f_3(n)\,f_{4422}^{-}\}+\frac{1}{5}\left\{[c_1(n)-c_1(nz)]\,f_{1432}^{-}+6s_1(nz)\,f_{1331}^{-}+\left\{12\,\frac{f_3(n)}{c_1(n)}+7\,[c_2(n)-c_2(nz)]\right\}f_{1234}^{+}\right\},\end{aligned}$$

$$\begin{aligned}4nc_1^2(n)\,\mathrm{Im}\,h_1={}&2\left[c_2(n)\,nz-\frac{4}{5}\,s_2(nz)\right]f_{1334}^{-}+\frac{nc_2(n)-s_2(n)}{c_1(n)}\\&\times\{[f_1(n)+1]\,f_{4422}^{-}-f_3(n)\,f_{2442}^{+}\}+\frac{1}{5}\left\{7\,[c_2(n)-c_2(nz)]\,f_{1432}^{-}+\left[12\,\frac{f_1(n)+1}{c_1(n)}-c_1(n)+c_1(nz)\right]f_{1234}^{+}-6s_1(nz)\,f_{1133}^{+}\right\}.\end{aligned}$$

Here $c_{1,2}(\xi)=\cosh\xi\pm\cos\xi$; $s_{1,2}(\xi)=\sinh\xi\pm\sin\xi$; $f_1(\xi)=\cosh\xi\cos\xi$, $f_{2,4}(\xi)=\cosh\xi\sin\xi\pm\sinh\xi\cos\xi$, $f_3(\xi)=\sinh\xi\sin\xi$; $f_{glms}^{\pm}\equiv f^{\pm}(\nu,z)=f_g(\nu)f_l(\nu z)\pm f_m(\nu)f_s(\nu z)$.

As shown in Fig. 1, t_1, as well as the moduli and phases of e_1, h_1, and f_1, have been analyzed as functions of z, calculated, and plotted, for various values of the parameter ν; the limiting cases have been investigated in detail. The conditions under which the obtained approximation could be used were also established.

CALCULATION OF THE TURBULENT CHARACTERISTICS OF FLOW IN A PLANE CURVILINEAR DUCT

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UDC 532.54

We consider the steady-state circular motion of an incompressible viscous fluid under pressure in a plane curvilinear duct. The following equations hold for this type of flow: $v_x = v'_x$; $v_r = v'_r$; $v_\varphi = \overline{v_\varphi} + v'_\varphi$; $p = \overline{p} + p'$; $\overline{v}_x = \overline{v}_r = 0$; $\overline{v}_\varphi = v_\varphi(r)$; $\overline{p} = p(r, \varphi)$; and the derivatives of the averaged variables with respect to the coordinates x and φ vanish at zero (except that $\partial\overline{p}/\partial\varphi \neq 0$).

The equations for the components of the correlation tensor $\overline{v'_i v'_j}$ have the same form as for the case of circular flow between rotating cylinders [1].

In the derivation of the equations we used semiempirical relations for the dissipation of fluctuation motion:

$$D=2\nu\sum_{k=1}^{3}\overline{\frac{\partial v'_i}{\partial x_j}\cdot\frac{\partial v'_j}{\partial x_i}}=\nu c_1\frac{\overline{v'_i v'_j}}{l^2}+\delta_{ij}\frac{2c}{3}\cdot\frac{E^{3/2}}{l^2}$$

and for the exchange of energy between different components of the velocity fluctuations [2]:

$$\frac{1}{\rho}\overline{p'\left(\frac{\partial v'_i}{\partial x_j}+\frac{\partial v'_j}{\partial x_i}\right)}=-k\frac{\sqrt{E}}{l}\left(\overline{v'_i v'_j}-\delta_{ij}\frac{2}{3}E\right).$$

In order for these equations to be closed they must be augmented with the equation of average motion

$$\frac{d}{dr}\left(\overline{v'_r v'_\varphi}r^2\right)=\nu\frac{d}{dr}\left[r^3\frac{d(\overline{v}_\varphi/r)}{dr}\right]-\frac{\tau}{\rho}\cdot\frac{\partial\overline{p}}{\partial\varphi}\quad\left(\frac{\partial\overline{p}}{\partial\varphi}=\text{const}\right)$$

and the turbulence scale l must be determined.

In order to simplify the calculations we consider separately the flow domains near the duct walls, where $\overline{v}_\varphi/r \ll \partial\overline{v}_\varphi/\partial r$ and, therefore, $\mathrm{Re}_{\omega l} \ll \mathrm{Re}_l$, and in the central part of the flow, where the motion approximates potential flow, $\overline{v}_\varphi r = \beta = \text{const}$, and it is permissible to let

$$\mathrm{Re}_l+\mathrm{Re}_{\omega l}=\frac{l^2}{\nu}\cdot\frac{1}{r}\cdot\frac{d}{dr}(\overline{v}_r r)\approx 0.$$

The distributions of the average velocity, turbulent friction stress, fluctuation intensities of the velocity vector components, and other characteristics exhibiting good agreement with experiment [3-4] are obtained on integrating the derived equations.

The analytical equations have the form

$$\frac{\sqrt{\overline{v_x'^2}}}{v_{*i}}=\left[2-\frac{4/3\,(k/c-1)\,\mathrm{Re}_E}{(k/c)\,\mathrm{Re}_E+c_1/c}-\frac{2\,(\mathrm{Re}_E+c_1/c)}{(k/c)\,\mathrm{Re}_E+c_1/c}\right]^{1/2};$$

$$\frac{\sqrt{\overline{v_r'^2}}}{v_{*i}}=\left[\frac{2/3\,(k/c-1)\,\mathrm{Re}_E}{(k/c)\,(\mathrm{Re}_E+c_1/c)}\right]^{1/2}\frac{\mathrm{Re}_E}{\left(\frac{lv_{*i}}{\nu}\right)};$$

$$\frac{\sqrt{\overline{v_\varphi'^2}}}{v_{*i}}=\left[\frac{2/3\,(k/c-1)\,\mathrm{Re}_E}{(k/c)\,\mathrm{Re}_E+c_1/c}+\frac{2\,(\mathrm{Re}_E+c_1/c)}{(k/c)\,(\mathrm{Re}_E+c_1/c)}\right]^{1/2}\frac{\mathrm{Re}_E}{\frac{lv_{*i}}{\nu}};$$

$$\frac{\overline{v'_r v'_\varphi}}{v_{*i}^2}=\frac{-c\,\mathrm{Re}_E+c_1}{\mathrm{Re}_l}\quad\frac{\mathrm{Re}_E^2}{\left(\frac{lv_{*i}}{\nu}\right)^2}.$$

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for flow near the walls, and

$$\frac{\sqrt{\overline{v'^2}}}{v_{*i}} = \left[2-2kc^{1/3} + \frac{4l^{2/3}\,\mathrm{Re}_{\omega l}}{k\,\mathrm{Re}_E}\right]^{1/2} \frac{\mathrm{Re}_E}{\frac{lv_{*i}}{\nu}};$$

$$\frac{\sqrt{\overline{v_r'^2}}}{v_{*i}} = \left[kc^{1/3} - \frac{4c^{2/3}\,\mathrm{Re}_{\omega l}}{k\,\mathrm{Re}_E}\right]^{1/2} \frac{\mathrm{Re}_E}{\frac{lv_{*i}}{\nu}};$$

$$\frac{\sqrt{\overline{v_\varphi'^2}}}{v_{*i}} = k^{1/2}\,c^{1/6}\,\frac{\mathrm{Re}_E}{\frac{lv_{*i}}{\nu}};$$

$$\frac{\overline{v_r'\,v_\varphi'}}{v_{*i}} = c^{2/3}\,\frac{\mathrm{Re}_E^2}{\frac{lv_{*i}}{\nu}}$$

for the potential flow domain.

NOTATION

E	is the fluctuation kinetic energy;
l	is the turbulence scale;
c_1, c, k	are empirical constants;
δ_{ij}	is the Kronecker delta;
$\overline{v}_x$, $\overline{v}_r$, $\overline{v}_\varphi$, $\overline{p}$, v_x', v_r', v_φ', p'	are the average and fluctuation values of the velocity vector components and pressure, respectively;
ρ	is the density;
ν	is the kinematic viscosity coefficient;
η	is a universal coordinate;
τ_1, τ_2	are the tangential friction stresses at the walls;
v_{*i}	is the dynamic velocity;
$\mathrm{Re}_l = (l^2\,\partial^2\overline{v}_\varphi/\partial r)/\nu$;	
$\mathrm{Re}_{\omega l} = (l^2\overline{v}_\varphi/r)/\nu$;	
$\mathrm{Re}_E = l\sqrt{E}/\nu$	are dimensionless local criteria.

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HEAT TRANSFER IN THE NUCLEATE BOILING OF FREE-FLOWING LIQUID FILM

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UDC 536.242

The principal mechanism responsible for heat transfer in the nucleate boiling of a free-flowing film at moderate heat inputs is convection. The heat-transfer process can therefore be described by means of the following equation from the semiempirical theory of turbulent heat transfer:

$$\frac{\alpha}{\lambda}\cdot\frac{\nu}{u_*}=\frac{\mathrm{Pr}}{\psi},$$

provided that the dynamic velocity u_* is expressed in terms of the total energy dissipation E_0 in the layer adjacent to the wall, in the form $u_* = \sqrt[4]{\nu E_0/\rho}$. Here λ, ν, and ρ are the thermal conductivity, kinematic viscosity, and density of the liquid; and Pr is the Prandtl number.

In the case of boiling of a free-flowing film the quantity E_0 consists of the energy dissipation due to flow of the film and the dissipation due to the rapid growth of vapor bubbles on the heat-exchange surface [1].

The heat-transfer equation deduced from these assumptions appears as follows after transformation to a form suitable for engineering calculations:

$$\frac{\alpha}{\alpha_0}=\sqrt[3]{1+\left(\frac{\alpha_b}{\alpha_0}\right)^3},$$

where α_0 is the heat-transfer coefficient for free flow of the film and α_b is the heat-transfer coefficient for boiling of the liquid in a thin film and may be assumed to be proportional to the heat-transfer coefficient α_{pb} for pool boiling, i.e.,

$$\alpha_b=a\,\alpha_{pb}.$$

The value of the proportionality factor a is determined experimentally.

The validity of Eq. (1) was tested experimentally on a system the principal working component of which is a stainless steel (steel 1Kh18N9T) tube 1 m in length. An electric heater is located inside the tube. The liquid, preheated to the boiling point, was made to flow in a film over the exterior surface of the tube. The experiments were conducted with ethyl alcohol at atmospheric pressure.

The validity of Eq. (1) was also confirmed by comparison with the experimental data obtained in [2] for film boiling of water on the interior surface of a copper tube.

It was established by comparison of the data of Eq. (1) with the experimental results that the proportionality factor a in expression (2) may be assumed to be constant and equal to 0.5.

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EFFECT OF RADIATION ON HEAT TRANSFER IN PLANE LAYERS OF LIQUID

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UDC 536.3

In the measurement of heat conduction coefficients of liquids special attention has recently been turned to errors connected with the effect of radiation.

In this article the results of a study of temperature fields in plane layers of liquid in the absence of free convection are presented and a tentative evaluation of the radiant component of the effective coefficients of heat conduction of 11 liquids (saturated hydrocarbons, alcohols, toluene, benzene, and water) is given.

The temperature fields were constructed from interferograms taken on an IAB-451 instrument, converted into a diffraction interferometer. An LG-75 optical quantum generator [1] was used as the light source.

The effective coefficients of heat conduction of the liquids were measured by the relative method on a plane layer. The thickness of the layer studied varied over the interval from $\delta = 1.20$ to 6.00 mm. All the studies were conducted in the region of room temperatures; the temperature difference at the boundary layers was from 0.5 to 5.0°K.

The interferograms and temperature distributions constructed from them (Fig. 1) graphically show that under the same conditions the temperature distributions in water and octane have different natures. For octane, as well as for all the saturated hydrocarbons, toluene, and benzene studied, the temperature distribution represents a curve the nature of which depends on the thickness of the layer studied, the temperature difference at the boundaries, and the optical properties of the medium. For water and alcohols, which absorb strongly in the infrared region of the spectrum, the temperature distribution always remains linear.

A monotonic dependence of the effective coefficient of heat conduction of saturated hydrocarbons, benzene, and toluene on the thickness of the layers studied was discovered. The dependence obtained

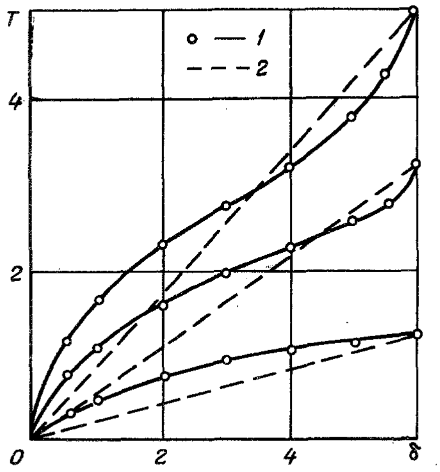

Fig. 1. Interferograms of temperature fields in layers of water (a) and octane (b, c) and temperature distributions constructed from them: 1) octane; 2) water.

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allowed a tentative evaluation of the magnitude of the radiant component of the effective heat-conduction coefficient. This value was negligibly small for water and alcohols, while for saturated hydrocarbons, benzene, and toluene under the conditions of our experiment it was from 3.7 to 7.6%.

Thus, the experimental results showed that, in the room temperature region radiant heat exchange, accompanying the molecular heat conduction, can affect in a marked fashion the temperature distribution and effective coefficient of heat conduction of liquids.

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THE EQUIVALENT THERMAL CONDUCTIVITY OF A STACK OF SHEETS OF ELECTROTECHNICAL STEEL

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UDC 536.21:621.3.042.2

Equivalent thermal conductivities are given in Table 1 for packs of transformer sheet steel of grades É31, É44, and Hyperco; the values are for compression up to $2.8 \cdot 10^7$ N/m^2 at 60-180°C and heat fluxes of 0.98-4.4 W/cm^2 (Fig. 1).

A description is given of the apparatus, the experimental methods, and the calculations, and also a roughness tests.

An analysis of the experimental results shows that the equivalent thermal conductivity increases with the pressure on account of reduction in the contact resistance. The change is largest up to $8 \cdot 10^6$ N/m^2.

The temperature also affects λ_e; low p_c means that much of the heat is transmitted through the air films, and the effects of temperature are then most prominent. The transfer is controlled by the elastoplastic behavior at higher p_c, and the decisive feature is the number of contact spots; the effects of temperature are then small.

TABLE 1. Basic Characteristics of the Packs

No.	Steel	Finish class	Treatment	Actual sheet thickness, mm	Sheet diameter, mm	Pack height, mm	Coating thickness, mm	Number of sheets
1	É31	3	Oxidation at 600°C in air for 1 h	0,4	37,91	5,6	—	14
2	É44	3	—	0,37	37,94	5,194	—	14
3	É44	3	Reduction at 900°C for 2 h, cooling with container to 200°C	0,37	37,94	5,194	—	14
4	Hyperco	7	—	0,365	38,02	5,11	—	14
5*	Hyperco	7	Coating with talc suspension	0,395/0,365	38,02	4,165	0,015	11

*Pack of five coated sheets and six uncoated sheets placed alternately.

S. Ordzhonikidze Aviation Institute, Moscow. Original article submitted November 23, 1970; abstract submitted December 31, 1970.

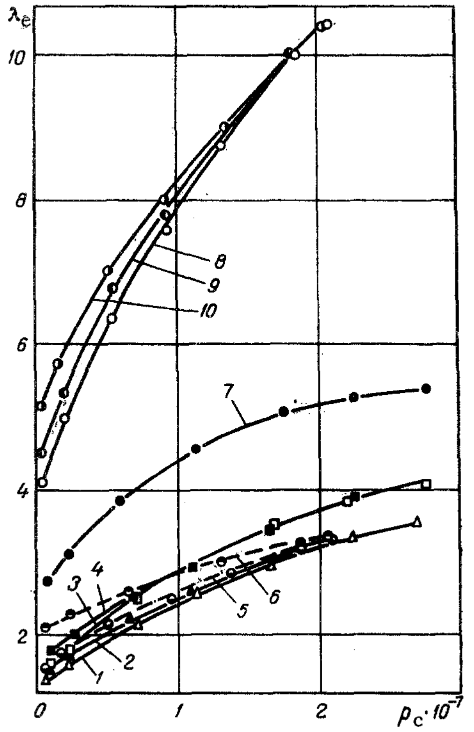

Fig. 1. Values of λ_e, W/m · deg, as functions of contact pressure p_c (N/m^2) for: 1-4) É44; 5, 6) É31; 7-10) Hyperco; 1) t = 106-115°C, q = 1.07-2.18 W/cm^2; 2) 151-164; 2.28-3.14; 3) 103-109; 1.89-2.76; 4) 154-163; 3.06-4.4; 5) 102-112; 1.29-1.98; 6) 161-180; 2.7-3.36; 7) 99-107; 1.77-2.44; 8) 60-66; 0.98-1.23; 9) 107-115; 2.04-2.52; 10) 165-174°C; 3.52-4.21 W/cm^2.

The results for É44 and Hyperco show that reduction increases λ_e by up to 15%, while talc coating reduces it by a factor 1.6-1.9.

The results can be used in calculations on laminated cores.

DETERMINATION OF THE DIFFUSION COEFFICIENT OF HYDROGEN IN METALS ACCORDING TO THE STATIONARY-FLOW METHOD

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and P. V. Gel'd

UDC 669.788:539.219.3

In the article an expression is obtained for the estimate of the optimal time of degassing of a sample between two successive measurements of the diffusion coefficient of hydrogen in metals according to the stationary-flow method.

In the case of a completely degassed sample, the length L intercepted on the time axis by the asymptote of the time dependence of the pressure of the gas diffusing into the volume V equals $l^2/6D$ (l is the sample thickness; and D is the diffusion coefficient). For the case of the same sample partially degassed during a time t' larger than the relaxation time, the relative deviation of this length from L is determined from the expression

$$\varepsilon \cong \frac{12}{\pi^2} \exp\left[-\frac{D\pi^2 t'}{l^2}\right].$$

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From this expression we can obtain the optimal degassing time of the sample, which enables us to determine a value of the diffusion coefficient with systematic deviation not exceeding ε.

APPROXIMATE SOLUTION OF A TEMPERATURE PROBLEM

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UDC 536.2.01

In the article a solution is presented for a temperature problem by an approximate method.

The main problem of the approximate method is the reduction of partial differential equations to a system of ordinary differential equations with the condition of minimum error of the solution. One of the most useful methods is the method of the quasistationary temperature distribution, in which it is assumed that the temperature field varies in the same way as does the temperature. However, it is impossible satisfactorily to describe the function for the variation of the temperature field over the entire time interval by the first-order equation that relates the temperatures of interest to us.

In the article a method using a second-order equation is suggested for decreasing the error of the solution obtained. As an example we take a single-layer plate with heat release, thermally insulated on one side and washed by a coolant flow on the other side. A system of ordinary differential equations relates the plate temperature averaged over the cross section and the perturbations (internal sources of heat release and temperature of the cooling coolant) in nonstationary conditions.

Calculations show that a small complication in the system of equations leads to a more exact solution of the temperature-calculation problem (the variability of the coefficient of heat exchange is allowed for in the equations). Figure 1 gives a comparison between the approximate solution obtained and the exact solution [1]. We see from Fig. 1 that for large times the exact and approximate solutions agree, and for small times our second-order approximation differs only very slightly from the exact solution, whereas the quasistationary solution gives qualitatively incorrect results.

The proposed method can be used also for more complex systems – a multilayer plate, a cylinder, and others with two-sided heat exchange, with distributed heat sources, etc.

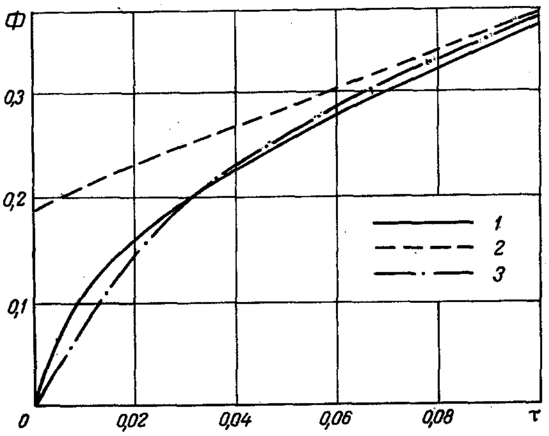

Fig. 1. Variation of mean temperature of plate for temperature jump on the surface: 1) exact solution; 2) quasistationary solution; 3) second-order approximation.

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CALCULATION OF TEMPERATURE FIELDS OF SOLIDS PLACED IN A CONTAINER, WITH NONLINEAR BOUNDARY CONDITIONS

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UDC 536.24

The problem of determining the nonstationary temperature field of a material inside a metal container, when the heat flux outside is related to the temperature of the container surface by a nonlinear function, reduces to the solution of a nonlinear Volterra integral equation, second order with respect to the temperature of the container. To simplify the solution of the obtained integral equation we consider two periods – quasistationary and initial. For the quasistationary conditions an exact analytical solution is obtained. The initial period is investigated using the integral method. Calculation formulas are given for the case of radiative–convective heating. The solutions obtained enable us, for high-temperature heating conditions, to take account of the effect of the specific heat of the container on the temperature distribution in solids of classical shape inside the container.

MATHEMATICAL DESCRIPTION OF TRANSIENTS IN THERMOELECTRIC POWER SOURCES WITH DISTRIBUTED PARAMETERS

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and A. E. Solov'ev†

UDC 621.362

Increased power and performance in thermoelectric power sources require one to consider the temperature gradients at heat-transfer surfaces on account of cooling of the heat carrier and heating of the coolant at finite flow rates. This requires a mathematical description of the transients that incorporates this gradient.

The temperature is represented by continuous functions with piecewise-continuous derivatives up to the second order, inclusive.

The transients in a system with flat elements are described by a system of nonlinear inhomogeneous equations of parabolic type incorporating the Peltier, Thomson, and Joule effects in the presence of gradients at the surfaces.

Analytic expressions are derived for the current, voltage, and power in terms of the temperature distribution in the elements for the following cases:

1. The electrical parameters are expressed via integral mean characteristics for the temperature distributions. The units are joined in series and the load is resistive. There is negligible insulation leakage.
2. As 1, but leakage must be considered.
3. The electrical parameters are defined in terms of the temperature distribution on the basis of constant temperature gradient along the y axis, with the partial derivatives replaced by finite-difference relations. The load is resistive and the leakage is negligible.

The equations allow one to simulate on a computer the transients in the elements and the power source.

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†Original article submitted November 2, 1970; abstract submitted January 27, 1971.

A TURBULENT AIR JET PASSING THROUGH A SEMIPERMEABLE OBSTACLE

V. F. Dunskii and L. I. Mondrus

UDC 532.517.4

There are various technical problems involving passage of turbulent jets through permeable obstacles. A study has already been made [1] of passage through a planar grating, and here we consider the more general case of passage through a semipermeable layer.

The momentum M is constant in the incident part of the jet, but it decreases in the layer. The decrease in a distance dx is

$$dM = -\xi M dx, \tag{1}$$

where ξ is a constant for the layer and characterizes the permeability.

We solve this equation and assume that the velocity profile remains similar in an axially symmetric jet, so that the boundaries remain rectilinear [2]; we also assume that the profiles correspond approximately to that for the unperturbed jet [2], which gives us an equation for the air flow through an arbitrary cross section within the layer:

$$Q_2 \approx 0.484\, U_0 R_0 x \exp\left[-\frac{\xi (x - x_1)}{2}\right]. \tag{2}$$

It follows from (2) that the flow rate increases with x for $x = x_1$, and also that $Q_2 \to 0$ for $x \to \infty$. The flow rate initially increases with x but then decreases; but the latter is physically impossible, so the above assumptions about the velocity profile are physically possible only if the air flow rate within the layer increases with x. The critical layer thickness is then

$$\Delta x_{\mathrm{cr}} = \frac{2}{\xi} - x_1. \tag{3}$$

If the thickness exceeds this, we assume that the rate is constant, which means that the boundaries must be curvilinear, and the jet expands more rapidly than does an unperturbed one.

The critical thickness becomes negative if $2/\xi < x_1$, which means physically that the jet is unable to overcome the obstacle completely when there is a layer of low permeability fairly remote from the nozzle. The layer transmits only part of the jet, as in [1].

These results are confirmed qualitatively by photographic tests on jets, and quantitatively by the profiles of the total and static pressures in front of the layer and behind it.

NOTATION

M	is the momentum;
ξ	is the layer permeability;
x	is the distance from the initial section of jet;
x_1	is the distance from that section to the front of the layer;
Δx	is the layer thickness;
Δx_{cr}	is the critical layer thickness;
R_0	is the nozzle radius;
U_0	is the mean air speed in the initial section;
Q_2	is the air flow rate in the cross section.

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All-Union Scientific-Research Institute of Phytopathology, Moscow. Original article submitted September 16, 1970; abstract submitted November 23, 1970.

PARAMETERS OF NONEQUILIBRIUM PLASMA JET OF HIGH FREQUENCY DISCHARGE IN HELIUM

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UDC 533.932

An experimental study is presented of the parameters of a subsonic nonisothermic rarefied plasma jet generated by a coaxial source at a frequency of 7 MHz at pressures in the working chamber of 0.03, 0.09, and 0.15 mm Hg and magnetic fields of 40, 30, 25, and 20 Oe in the measuring region. On the axis in the center of the source, the magnetic field was equal to 800 Oe. A thermoanemometer adapter, a Langmuir probe with a molybdenum fiber 0.09 mm in diameter and 17 mm long, was used in all the measurements. The temperature $T_W = T_W(V)$ and volt–ampere $I_\Sigma = I_\Sigma(V)$ characteristics of the adapter fiber were read at distances of 50, 75, 100, and 125 mm from the output opening of the source along the jet axis.

For treatment of the electron component the probe characteristics were measured by the Langmuir method. On the other hand in a subsonic jet where $U_\infty \lesssim \sqrt{kT_e/m_i}$, the plasma potential

$$\varphi_0 \approx \varphi_{I_\Sigma=0} + \frac{kT_e}{e} \ln \left(\frac{0.7 \sqrt{m_i/m_e}}{1+0.97\, S_{ei}} \right)$$

and the concentration of charged particles

$$n_i \approx I_i/0.4e\; 2\pi a L \sqrt{2kT_e/m_i}\; \mathrm{erf}\; (\sqrt{\eta}\, R/a)$$

can be determined from the ion part of the probe characteristics. (Here $\eta = eV/kT_e$, $S_{ei} = U_\infty \sqrt{m_i/2kT_e}$, and a is the radius of the electrode layer.) It must be noted that the concentration of ions n_i was systematically 1.2-1.4 times lower than the concentration of electrons n_e found by the Langmuir method.

The values of the plasma potential determined by the Langmuir method and calculated from Eq. (1) are found to be in good agreement.

The velocity ratio S_n was calculated from the values

$$S_n \approx \left\{ \frac{\gamma}{\gamma - 1} \left[\left(\frac{p_0}{p} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \right\}^{0.5},$$

of the measured pressure in the source p_0 and the static pressure in the jet p. The maximum error in determining S_n did not exceed ±10%.

The temperature T_n of the neutral particles was determined from the level of the energetic balance of the fiber. The maximum relative error in determining T_n did not exceed ±18%.

The values of T_n found made it possible to evaluate the mass velocity of the jet $U_\infty \approx 800$, 600, and 480 m/sec and the concentration of neutral particles $n_n \approx 0.76$, 2.01, and $3.29 \cdot 10^{15}$ cm^{-3} at p = 0.03, 0.09, and 0.15 mm Hg, respectively.

The analysis of volt–ampere and temperature characteristics of the thermoanemometer–Langmuir probe made it possible to obtain the distribution of the basic local parameters: temperature of electrons T_e, ions T_i, and neutral particles T_n, the concentration of charged particles, and the plasma potential along the jet. The results of the studies showed that an increase in discharge and gas pressure leads to a decrease in the temperature of the charged particles, the Mach number, and the velocity of the jet, and increases the temperature of the neutral gas. The decrease in the temperature of the charged particles along the jet was accompanied by a slight decrease in the degree of ionization. The temperature of the neutral gas along the jet remained constant within the limits of measurement error.

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TEMPERATURE DEPENDENCE OF THE DAMPING COEFFICIENTS FOR A DYNAMICAL SYSTEM WITH A SINGULAR KERNEL

S. I. Meshkov and Yu. A. Rossikhin

UDC 532.135

Algebraic equations in fractional powers are the characteristic equations encountered for damped free oscillations in a one-mass system the memory effect of which is represented by weakly singular kernels. If the kernels are of Abel, Rabotnov, or Rzhanitsyn aftereffect type, the characteristic equations do not have real roots on the first sheet of the Riemann surface and so they cannot be used to describe aperiodic damping. It is found from the roots and the retardation and relaxation spectra that there is a region of aperiodic motion only if the system has its δ-function singularities confined to the relaxation-time spectrum.

An example is considered of a Rzhanitsyn relaxation kernel, for which the following is the initial equation of motion in tersm of the displacement x after a pulse $F\delta(t)$:

$$\ddot{x}+\omega_{\infty}^{2}x-\left(\omega_{\infty}^{2}-\omega_{0}^{2}\right)\int_{0}^{\infty}R(t')\,x(t-t')\,dt'=F\delta(t). \tag{1}$$

Here ω_∞ and ω_0 are the natural frequencies of the unrelaxed and relaxed elastic vibrations, while R(t) is the relaxation kernel:

$$R(t)=\frac{t^{\gamma-1}\exp(-t/\tau_{\varepsilon})}{\Gamma(\gamma)\,\tau_{\varepsilon}}=\frac{\sin\pi\gamma}{\pi}\int_{0}^{\tau_{\varepsilon}}\frac{\tau^{\gamma-2}\exp(-t/\tau)\,d\tau}{(\tau_{\varepsilon}-\tau)^{\gamma}}, \tag{2}$$

$$0<\gamma\leqslant 1.$$

By analogy with a standard linear body ($\gamma = 1$), the solutions to (1) with the properties of (2) described vibrational and limitational motions. The equilibrium position is determined by the retardation and inertial features via a Laplace transform, the distribution of which becomes that of the retardation times in the quasistatic case.

The behavior of the roots is examined in the principal complex plane, and it is found that Q influences the temperature dependence of the damping coefficients and of the corresponding amplitudes for the vibrational and limitational motions.

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