HEAT LIBERATION OF A MIXING LAYER OF LOOSE MATERIAL IN A VACUUM

A. G. Zeberin, V. V. Kornaraki,
and G. Ya. Pipkevich

UDC 536.255:535.5

Heat exchange is studied between a dense mixing layer and a surface under conditions of high ($<10^{-2}$ Pa) vacuum. The layer heat-liberation coefficient is determined by a method based on solving the problem of cooling of a compact isothermal mass, the upper part of which is under conditions of radiant heat exchange with the surroundings; and the lower part of which is under conditions of radiant and conductive heat exchange with an enclosing surface. The heat-exchange surface in the experiments was maintained at the temperature of boiling nitrogen. The temperature of the layer, the intensity of mixing, and the dispersion of the material were varied. The material used was four narrow fractions of type MSB microspheres of superhard lead glass.

Some results are shown in Fig. 1. The study presents the dependence of the heat-liberation coefficient on mixing speed and particle size. On the whole, the coefficient values agree with those known from other studies. A positive relationship between the heat-liberation coefficient and layer temperature was observed, which, however, was not unambiguous. For coarse fractions, the heat-liberation coefficient undergoes saturation with increase in mixing speed, which confirms the results of [1]. However, for the other fractions in the range studied, there appears only a tendency to saturation.

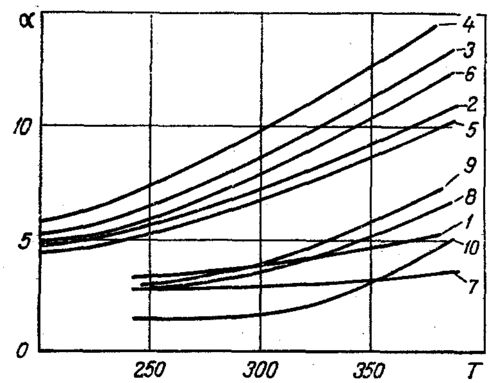

Fig. 1. Heat liberation coefficient α, W/m²°K versus temperature T, °K:

Curve	Mean grain size, μ	Mixer rotation speed, rpm
1,2,3, 4	28.0	1, 75; 9, 16;30
5, 6	52.0	9; 16; 30
7-9	90.5	1, 75; 9 and 16; 30
10	163.0	9; 16; 30

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Dep. 1162-77, March 5, 1977.
Original article submitted July 16, 1976.

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 33, No. 3, pp. 526-537, September, 1977.

 0022-0841/77/3303-1108$07.50

EFFECT OF NEGATIVE PRESSURE GRADIENTS ON BOUNDARY-LAYER CHARACTERISTICS IN GAS FLOW IN TUBES

V. N. Panchenko

UDC 532.542

Turbulent adiabatic gas flow in a round tube with infrasonic velocity at the input and crisis at the exhaust is studied.

Experimentally obtained longitudinal velocity profiles [1] are used to calculate the boundary-layer thicknesses δ^* and δ^{**}, the velocity profile form parameter $H = \delta^*/\delta^{**}$, and the number $Re_{\delta^{**}}$ for the developed turbulent flow segment. The longitudinal velocity profile u is approximated by a power function

$$u = u_1 y^n, \tag{1}$$

where the exponent n, according to the data of [1], decays rapidly, reaching a value on the order of 1/15 at the exhaust for a Reynolds number $Re \cong 5.5 \cdot 10^5$.

Calculations revealed that the thicknesses δ^* and δ^{**} decrease with increase in x, and the form parameter H increases with increase in the pressure-gradient parameter

$$\beta_{\delta^{**}} = \frac{\delta^{**}}{\tau_0}\left|\frac{dp}{dx}\right|.$$

Filling of the velocity profile upon approach to the exhaust leads to an increase in surface friction τ_0 and, consequently, to an increase in the friction coefficient

$$c_f = \frac{2\tau_0}{\rho_1 u_1^2} \tag{2}$$

with a decrease in $Re_{\delta^{**}}$ (Fig. 1). The τ_0 values required for determination of c_f with Eq. (2) were determined by the method described in [2].

The character of the change in H, $Re_{\delta^{**}}$, and the coefficient c_f qualitatively indicate the phenomenon of reverse transition in the flow of the compressed gas in the tube.

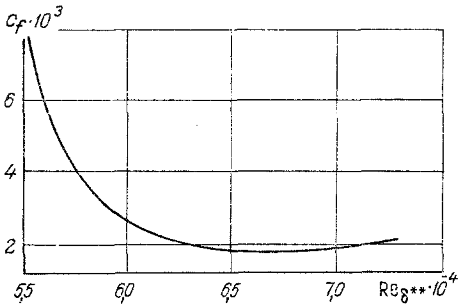

Fig. 1. Friction coefficient c_f versus $Re_{\delta^{**}}$.

NOTATION

c_f, friction coefficient; δ^*, displacement thickness; δ^{**}, momentum loss thickness; $H = \delta^*/\delta^{**}$, velocity profile form parameter; dp/dx, pressure gradient; Re, Reynolds number; u, longitudinal velocity component; x, longitudinal coordinate; y, transverse coordinate; ρ, density; τ, tangential stress. Indices: 0, tube wall; 1, tube axis.

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Dep. 1083-77, January 24, 1977.
Original article submitted January 14, 1975.

METHOD OF DETERMINING THE SURFACE TEMPERATURE OF A SPHERE

A. V. Kryanev, E. V. Saperov, and V. K. Fardzinov UDC 536.24.02

The problem formulated in this study is one of the class of incorrectly placed problems and concerns determination of the surface temperature of a sphere from measurements performed outside the sphere. To solve such problems a suitable regularizing algorithm must be found. In a number of cases, finding this algorithm is complicated, since the desired function, the sphere temperature $T_s(\tau)$, is not a sufficiently "smooth" monotonic function. For example, during the time period in which we are interested the changes in sphere temperature $T_s(\tau)$ may have one, two, or more "bulges," whose amplitude and change characteristics also may be unknown. Calculation methods for "smooth" cases do not permit a sufficiently accurate solution of such a problem.

For this solution we propose an algorithm which permits use of a priori information on the desired function in the following form:

$$T_s(\tau) = T_{ap}(\tau)\, y(\tau),$$

where $T_{ap}(\tau)$ is a function specified a priori and reflecting the character of the change in the desired function; $y(\tau)$ is a correction considering the nonmonotonicity of the function.

We assume that $y(\tau)$ is a smooth function and can be determined with the aid of smoothing regularizing algorithms.

When it is difficult to clarify the character of the change of the desired function, it may prove useful to initially use the regularized method of successive approximations to obtain an approximate solution to the original equation. Then, setting $T_{ap}(\tau) \equiv T_s^{[1]}(\tau)$ we perform a second calculation with the algorithm proposed here.

If the desired function $T_s(\tau)$ is a sufficiently "smooth" monotonic function, the proposed algorithm offers no advantages over usual solution methods, for example, the method of successive approximations.

Analysis of the numerical results obtained showed that, in the presence of "bulges" in the desired function, over the time interval considered the proposed method permits more effective processing of measurements and establishment of the function $T_s(\tau)$ with very high accuracy.

Dep. 1083-77, February 14, 1977.
Original article submitted July 16, 1976.

METHOD OF CALCULATING THE THERMAL REGIME IN CRYOSTATS WITHOUT NITROGEN COOLING

L. A. Grenaderova, V. G. Dan'ko,
G. A. Mushkina, and L. V. Nevenchannyi UDC 536.483:621.313.322-81

A method has been developed for calculation of thermal fields and liquid-coolant expenditure in a cryostat whose thermal bridges are cooled by a cold gas formed by boiling of a cryogenic liquid. The construction method considered has been used in a model of a 200-kW experimental cryoturbogenerator [1].

The method permits consideration of lateral external heat intake, variability of thermal bridge section over length, the temperature dependence of the heat-transfer coefficient of the cryostat wall with the gas, and the dependence of all thermophysical characteristics of the materials on temperature.

The internal wall of the vacuum sleeve, whose temperature field must be determined, is divided into three sections according to heat-exchange conditions (Fig. 1). The first region $0 \leqslant x \leqslant l_1$ is bounded by liquid helium, and the thermal flux from its surface evaporates the liquid; the second region $-l_1 \leqslant x \leqslant l_2$ is in direct contact with the baffles maintaining

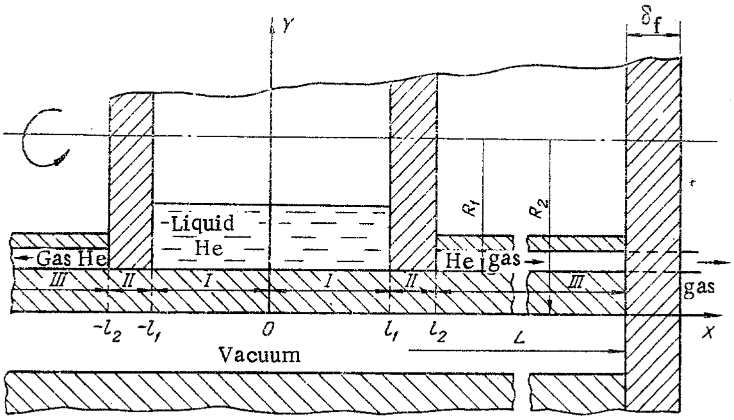

Fig. 1. Diagram of cooled regions.

the liquid in place. We will neglect the thermal flux leaving the sleeve into the baffle, assuming that the thermal flux passes through this region unchanged. The third region $l_2 \leq x \leq L$ is a slit-shaped channel formed by the walls of the vacuum sleeve and the thermal flanges. Cold gas formed by evaporation of the cryogenic liquid passes along this channel and cools the thermal bridges.

The thermal-conductivity equation for the first region is $\Delta T = 0$; for the second region, we have the requirement of constancy of thermal flux with continuity conditions for the function T(x) on the boundaries of the regions (at points $x = l_1$ and $x = l_2$). For the third region we solve the system of thermal-balance equations. The difference in thermal fluxes P(x) through sections x and $x + \Delta x$ in this region departs from the surface located between these sections and goes to heat the gas passing through the channel.

The problem is solved as follows. Given an arbitrary $T(l_2)$, we find the temperature distribution and liquid-coolant flow rate Q in the first region analytically. In the second region the temperature changes by a linear law. Then, knowing T(x), $T_b(x)$, and dT(x)/dx on the boundary of the third region (at $x = l_2$), from the thermal-balance equation we find the temperature distribution of the wall and gas along the entire channel by the method of successive steps. Comparing the calculated temperature value with that specified, we refine the arbitrarily chosen temperature $T(l_2)$, etc., until these values coincide with satisfactory accuracy.

The problem was solved numerically on a Minsk-22 computer.

An experimental study was also performed of the end segments of a cryostat with various constructional variants of the thermal flanges. Divergence between calculation and experiment was insignificant and within the limits of experimental error.

The good agreement between calculation and experiment confirms the possibility of wide use of the proposed method for further study of heat transfer in cryostats, not only in the static state, but in rotation as well.

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Dep. 1081-77, February 17, 1977.
Original article submitted December 15, 1975.

EFFECT OF POWER INSTABILITY ON THERMAL REGIMES IN ELECTRON-BEAM PROCESSING

V. K. Alekseev, V. V. Makarychev, and D. I. Cherednichenko

UDC 620.18:621.791.85

One of the basic parameters of electron-beam processing is the stability of beam power. A slight increase in energy or duration of the beam action produces a marked change in the dimensions of the melt zone in microdoping of semiconductors. Power pulsations also lead to waviness and inhomogeneities in the processed surface in polishing of monocrystals. On the other hand, the quality of beam processing depends not only on beam parameters, but on the thermophysical properties of the materials being processed. With growth in intensity of the irradiation, heat is liberated so rapidly that it cannot be dissipated by thermal conductivity, so that under these conditions one of the dominant factors affecting processing kinetics is the latent heat of evaporation. The critical energy density, at which the transition to the evaporation regime occurs for materials with poor thermal conductivity and low heat of evaporation, is low, and even small pulsations may lead to a spontaneous transition from the melting to the boiling regime or vice versa.

In connection with these facts, a detailed study of the thermal regime in processing in the presence of beam-power instability is of great interest. This study obtains formulas for determination of temperature-pulsation amplitude with a given instability, and quantitative estimates are performed for materials with varying thermophysical properties.

Considering the Gaussian distribution of energy over the beam section and the specified instability in the form of harmonic pulsations, for determination of temperature-oscillation amplitude at the maximum temperature point (r = 0) we have

$$\Phi(0, z) = \frac{q_0 \delta}{2\lambda} \sqrt{\frac{\pi}{k}} \exp\left[-(\alpha + i\beta)^2\right] \exp\left(i2\alpha z\sqrt{k}\right) \left\{1 + \frac{2i}{\sqrt{\pi}} \int_0^{\alpha + i\beta} (\sigma^2)\, d\sigma\right\} \exp\left(-2\alpha z\sqrt{k}\right),$$

$$\text{where } \alpha = \sqrt{\frac{\omega}{8ka}}; \quad \beta = \alpha + z\sqrt{k}.$$

Calculations performed with this formula show that at a beam power of 10^4 cal•cm^{-2}•sec^{-1} and 5% instability the temperature-oscillation amplitude comprises 4, 20, and 70°C in copper, germanium, and quartz, respectively.

It follows from analysis of the calculations that materials with low thermal conductivity are especially sensitive to pulsations, so that special requirements must be specified for the electron-beam equipment in their processing.

Dep. 1080-77, December 14, 1976.
Original article submitted March 31, 1975.

TRANSPORT AND SURFACE DRYING OF MOIST ROCK PIECES IN A THERMODYNAMIC OVERLOAD DEVICE

V. N. Lozinskii, Yu. S. Pukhov, and Yu. D. Khechuev

UDC 622.271:622.648

The effectiveness of using equipment, especially belt conveyors, is severely degraded by transport of very moist gummy rock. The adhesion of rock onto vessels and belts leads to a sharp increase in downtime and a drop in productivity of transport complexes. Existing methods and mechanisms for combatting rock adhesion in especially complex geological situations are not very effective.

One of the promising methods of preventing rock adhesion is intense surface drying of the rock by high-velocity hot gases of a reactive motor in the process of transporting the pieces in the turboduct of a thermodynamic overload device. The study presents a diagram of the device. The rock being loaded is picked up by the gas flow, transported along the tube, and dried on the surface. To reduce the resistance of the rock, the pieces being transported should move in the suspended state, which is ensured by at least a minimum critical gas-flow velocity

$$V_{\max} = \sqrt{\frac{2P_{\mathrm{p}}}{c_y \rho S_{\mathrm{p}}}} = \sqrt{\frac{2m_{\mathrm{p}} g}{c_y \rho S_{\mathrm{p}}}}.$$

The gas velocity which will ensure the necessary thickness of the dried layer on the surface of the pieces is given by

$$V_{\max} = \frac{\mu}{d_{\mathrm{p}}} \left\{ \frac{c \rho_{\text{м}} u_{\mathrm{c}} (W_{\text{н}} - W_{\mathrm{p}}) [d_k^3 - (d_{\mathrm{p}} - 2h_{\mathrm{e}})^3}{0.023 \lambda \pi \rho (T_{\text{т}} - T_{\text{п}}) d_k^4 \mathrm{Pr}^{0.33}} \right\}^{1.2}.$$

The final velocity of the rock pieces depends on their size, the duct length- and the gas-flow parameters.

$$V_{\mathrm{Pf}} = \frac{V_{\max} \sqrt{\frac{c_x \rho S_{\mathrm{p}} L}{m_{\mathrm{p}}}}}{1 + \sqrt{\frac{c_x \rho S_{\mathrm{p}} L}{m_{\mathrm{p}}}}}.$$

Experiments were performed with an experimental thermodynamic device using an RD-3M reactive motor. Rock of 25% moisture in pieces up to 350-400 mm in diameter was loaded. The turboduct length was 50 m, with a diameter of 1000 mm. Rock-flow output was 1500-2000 m^3/h. Gas flow in the tube reached 180-200 m/sec. The rock pieces were transported in the suspended state (their velocity reached 20-60 m/sec) and were dried to a depth of 1.5-2 mm, and surface moisture was not reestablished over the course of 1.5-2 h, eliminating adhesion.

The results of experimental and semiindustrial experiments show the technological possibility of using thermodynamic overload devices with reactive motors for intense surface drying of wet rock to eliminate the causes of adhesion in transport media.

Dep. 1079-77, November 22, 1976.
Original article submitted October 4, 1974.

CONVECTIVE DRYING KINETICS AND SELECTION OF INDUSTRIAL REGIMES

V. A. Kurochkin

UDC 66.047

The problem of the kinetics of convective drying of disperse materials in the initial period is considered. The analysis performed uses the postulate of instantaneous onset of the saturated state of the gas in the boundary layer of the particle or object being dried. This postulate is valid in the presence of free moisture on the surface of the material being dried.

Using a method developed previously by the author for analysis of drying kinetics in parallel flows by means of the auxiliary characteristic $K_0 = \Delta I/\Delta X$, it is possible to solve the problem of determining drying parameters in terms of the drying-temperature coefficient and the Rebinder criterion. For an arbitrarily specified moment in time we find

$$\left.\frac{d\bar{\vartheta}}{d\bar{u}}\right|_{\tau=0} = \frac{K_0 + c_{\mathrm{m}} \bar{\vartheta}}{c_{\mathrm{mat}} + c_{\mathrm{m}} \bar{u}} = K_0^*, \quad (1)$$

$$\mathrm{Rb} = \left.\frac{c_{\mathrm{m}}^* d\bar{\vartheta}}{r^* d\bar{u}}\right|_{\tau=0} = K_0^* \frac{c_{\mathrm{mat}}^*}{r^*}, \quad (2)$$

$$d\bar{\vartheta} = \frac{c_1}{c_2}\,dt, \tag{3}$$

where

$$c_1 = K_0^*\ , \quad c_2 = \frac{(1+\mathrm{Rb})\,r^*\mu}{c_h^*}\ .$$

The quantities appearing in Eqs. (1)-(3), ϑ, $\bar{u}$, t, I, X, c^*_h, c^*_{mat}, c_m, r^*, and μ represent, respectively, temperature and moisture content of the material; temperature, enthalpy, and moisture content of the heating agent; heat capacity of the heating agent and material; moisture and heat of evaporation of the moisture; and concentration coefficient of the flows.

A concrete example is used to demonstrate the significant effect of the initial period of disperse material drying on the overall course of the process.

The equation for drying kinetics in parallel flows, determining the heating-agent energy expenditure for heating of the moist material and its drying, can be used for selection of industrial regimes, for example, in tunnel dryers. It is shown that experiments on regime selection should be begun by relating the regime to the concrete parameters of the drying equipment and determining mass concentration of the material, product, and heating-agent flows.

Dep. 1161-77, February 28, 1977.
Original article submitted August 5, 1975.

SOLUTION OF REVERSE BOUNDARY PROBLEM FOR THE THERMAL-CONDUCTIVITY EQUATION BY THE METHOD OF DETERMINED MOMENTS

I. B. Basovich UDC 536.24.02

This study considers the reverse boundary problem of determining the thermal-conductivity coefficient of an inhomogeneous medium by measurements of temperature and thermal flux at boundary points. The equation of heat propagation and the system of boundary conditions have the form (with the coefficient of volume heat capacity considered constant and taken as unity for simplicity)

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

$$u_{t=0} = 0, \quad u_{x=L} = 0, \quad u_{x=0} = u_0(t), \quad \lambda(0)\left.\frac{\partial u}{\partial x}\right|_{x=0} = q(t),$$

where $\lambda(x)$ is the unknown thermal-conductivity coefficient.

Mathematically analogous problems also occur in the theory of liquid filtration through inhomogeneous porous media. We denote by τ_n and γ_n determined moments of temperature and thermal flux [1]

$$\tau_n = \int_0^\infty u_0(t)\,t^n dt\,, \quad \gamma_n = \int_0^\infty q(t)\,t^n dt, \ n = 0, 1, 2\ \ldots\ . \tag{2}$$

If the function q(t) is nonzero for a finite time interval, the integrals of Eq. (2) converge. We will consider iterated Green integrands $G_n(x, x_1)$ of the Sturm–Liouville operator on the right side of Eq. (1):

$$G_0(x, x_1) = \begin{cases} \int\limits_{x_1}^{L} \lambda^{-1}(x)\,dx, & x \leqslant x_1, \\ \int\limits_{x}^{L} \lambda^{-1}(x)\,dx, & x_1 < x. \end{cases} \quad (3)$$

Higher order integrands are determined from the recurrent relationships

$$G_n(x, x_1) = \int\limits_0^L G_{n-1}(x, \xi)\, G_0(\xi, x_1)\, d\xi, \quad n = 1, 2 \ldots . \quad (4)$$

Using the results of [2] for iterated Green integrands we obtain a diagonal system of linear equations

$$\tau_n = -\sum_{m=1}^{n+1} \frac{n}{(n-m+1)!} \gamma_{n-m+1} G_{m-1}(0, 0), \quad n = 0, 1, 2 \ldots . \quad (5)$$

From Eqs. (3)-(5) we can obtain expressions relating the unknown thermal-conductivity coefficient $\lambda(x)$ with the determined temperature and thermal flux moments.

In practical calculations of the determined moments the infinite integration interval is replaced by a finite one. An estimate is obtained of the error thus produced as a function of certain a priori constants limiting the thermal-conductivity coefficient and thermal flux value. Use of the determined moment method for solution of reverse problems is illustrated with the example of a piecewise-constant thermal-conductivity coefficient.

For the case indicated the regularity of the algorithm is proven in the presence of errors in the initial data. Results of the present study obtained for one-dimensional parabolic equations remain valid for axisymmetric problems.

NOTATION

$u(x, t)$, temperature; t, time; x, spatial coordinate; $\lambda(x)$, thermal-conductivity coefficient; τ_n, γ_n, determined moments of temperature and thermal flux; $G_n(x, x_1)$, iterated Green integrands.

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Dep. 1164-77, January 19, 1977.
Original article submitted January 19, 1976.

THREE-LAYER PROBLEM OF HEATING A THERMAL MAIN BY THE HEATING AGENT BEING TRANSPORTED

V. S. Shargorodskii, A. N. Kovalenko, and I. S. Tsvetkova UDC 536.242

The temperature problem of a thermal duct is examined with consideration of the interaction of layers of thermal insulation, metal, and heating agent, using the following formulation:

$$\frac{\partial t_m}{\partial \tau} = a_m \frac{1}{r} \frac{\partial}{\partial r}\left(r \frac{\partial t_m}{\partial r}\right), \quad r_1 \leqslant r \leqslant r_2, \quad (1)$$

$$\frac{\partial t_{ins}}{\partial \tau} = a_{ins}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t_{ins}}{\partial r}\right), \quad r_2 \leqslant r \leqslant r_3,$$

$$c_h\gamma_h\pi r_1^2 dz\frac{\partial t_h}{\partial \tau}\,d\tau = \left\{c_hG_h\left[t_h - \left(t_h + \frac{\partial t_h}{\partial z}\,dz\right)\right] - 2\pi r_1\alpha_1(t_h - t_m|_{r_1})\,dz\right\}d\tau,$$

$$-\left.\frac{\partial t_m}{\partial r}\right|_{r_1} = \frac{\alpha_1}{\lambda_m}(t_h - t_m|_{r_1}), \quad -\left.\frac{\partial t_{ins}}{\partial r}\right|_{r_3} = \frac{\alpha_3}{\lambda_{ins}}\left.t_{ins}\right|_{r_3}, \tag{1}$$

$$t_m(r_2) = t_{ins}(r_2) = t_2, \quad \lambda_m\left.\frac{\partial t_m}{\partial r}\right|_{r_2} = \lambda_{ins}\left.\frac{\partial t_{ins}}{\partial r}\right|_{r_2},$$

$$t_m|_{\tau=0} = t_{ins}|_{\tau=0} = t_{med} = 0, \quad t_h|_{z=0} = t_{h0}.$$

Equation (1) is solved with the expansion

$$t_m = \sum_{k=0}^{\infty}\frac{\partial^k t_2}{\partial \tau^k}R_{km}(r), \quad t_{ins} = \sum_{k=0}^{\infty}\frac{\partial^k t_2}{\partial \tau^k}R_{kins}(r). \tag{2}$$

As a result, recurrent equations are obtained for the radial functions R_{km} and R_{kins}:

$$R_m = \frac{1}{a_m}\int\frac{1}{r}\int rR_{(k-1)m}\,dr dr, \quad R_{kins} = \frac{1}{a_{ins}}\int\frac{1}{r}\int rR_{(k-1)ins}\,dr dr. \tag{3}$$

The problem is then solved using Laplace transforms:

$$T(s) \equiv \int_0^{\infty} t\exp(-s\tau)\,d\tau, \quad T_m = \sum_{k=0}^{\infty}s^kT_2R_{km}, \quad T_{ins} = \sum_{k=0}^{\infty}s^kT_2R_{kins},$$

$$T_h = T_{h0}\exp(-\varphi s)\exp[f(W|_{r_1} - 1)], \quad W = \frac{\sum_{k=0}^{\infty}R_{km}s^k}{\sum_{k=0}^{\infty}\Omega_k s^k}, \tag{4}$$

$$\Omega_k = R_{km}(r_1) - \frac{\lambda_m}{\alpha_1}, \quad \varphi = \frac{\pi r_1^2\gamma_h z}{G_h}, \quad f = \frac{2\alpha_1\pi r_1 z}{c_h G_h}.$$

The transformation to the original variables is accomplished with limitation to two or three terms in the transfer function W in light of the good convergence of the series

$$t_h = \exp(-\xi)\int_0^{\eta}\left(\frac{dt_{h0}}{d\eta} + t_{h0}\right)\exp(\eta - \mu)\,I_0\left[2\sqrt{(\xi - \beta)(\eta - \mu)}\right]d\mu,$$

$$\xi = f\frac{\Omega_1 - R_{1m}}{\Omega_1}, \quad \eta = \frac{\Omega_0}{\Omega_1}(\tau - \varphi), \quad \beta = f\frac{\Omega_0 - R_{0m}}{\Omega_0}. \tag{5}$$

The study presents finite formulas convenient for engineering use, and a nomogram of duct temperature fields for discontinuous and linear laws of t_{h0} change in the duct input section, as well as a comparison of solutions using different numbers of terms in the transfer function. The results permit evaluation of the effect of heat accumulation on the metal and insulation, and the effect of insulation quality on heating-agent temperature change. The duct length can thus be evaluated in this respect.

NOTATION

t, temperature; r, z, coordinates; τ, time; λ, c, γ, a, thermophysical properties of materials; G, heating-agent flow rate; α, heat-liberation coefficient. Indices: m, metal; ins, insulation; h, heating agent; med, medium; 0, initial duct section; 1, 2, 3, boundaries between materials.

Dep. 1160-77, February 25, 1977.
Original article submitted November 11, 1975.

STABILITY OF A SHEAR LAYER OF DILATANT LIQUID WITH SUCTION

L. I. Ionochkina, S. L. Simkhovich, and N. V. Filin

UDC 532.51:532.135

The hydrodynamic stability of a shear layer of dilatant liquid above a porous plate moving with a constant velocity U_0 in the presence of constant suction with a velocity V_0 is analyzed within the framework of the linear theory. Here the dimensionless velocity profile of the shear layer has the form

$$U(y) = (1+y)^{\frac{n}{n-1}}, \tag{1}$$

where U_0 is the characteristic velocity of the plate, $L = \frac{n}{n-1}\left(\frac{K_n}{\rho V_0 U_0^{2-n}}\right)^{\frac{1}{n}}$ is the characteristic size, determined from the condition $U(-1) = 0$, and $L \to 0$ as $V_0 \to 0$.

The study of the hydrodynamic stability of such flow comes down to the solution of an equation of the Orr–Sommerfeld type for the amplitude of a perturbation $\psi(y)$ in the stream function $\psi(x, y, t) = \psi(y) \exp[i\alpha(x - ct)]$:

$$E\psi = \frac{1}{Re_n}\left(\frac{n-1}{n}\right)^n (D^2-\alpha^2) D\psi \quad (-1 \leqslant y \leqslant 0). \tag{2}$$

Here

$$E \equiv (U(y) - C)(D^2-\alpha^2) - D^2U + \frac{i[(DU)^2]^{\frac{n-3}{2}}}{\alpha \mathrm{Re}_n} \langle (DU)^2 n (D^2-\alpha^2) +$$
$$+ (n-1)\{2n(DU)(D^2U)D^3 + [4\alpha^2(DU)^2 + n(DU)(D^3U) + n(n+2)(D^2U)^2]D^2 +$$
$$+ 2(n-2)\alpha^2(DU)(D^2U)D + \alpha^2 n[(DU)(D^3U) + (n-2)(D^3U)^2]\} \rangle ;\ D \equiv \frac{d}{dy};$$

$\mathrm{Re}_n = (\rho U^{2-n} L)/K_n$ is the generalized Reynolds number for a liquid with a power-law rheological law.

The boundary conditions for Eq. (2) consist in the equality to zero of both components of the perturbed motion at the wall $y = 0$ and at a large distance from the wall $y = -\infty$:

$$\psi(0) = \psi'(0) = 0; \quad \psi(-\infty) = \psi'(-\infty) = 0. \tag{3}$$

At the point $y = -1$ the viscous flow is joined with the external flow, where $U = \text{const}$. The equation for the perturbation $\psi(y)$ in the external flow is written in the form

$$(D^2-\alpha^2)\psi = 0. \tag{4}$$

The solution of Eq. (4) satisfying the conditions (3) has the form $\psi = Ae^{-\alpha y}$, so that in the solution of Eq. (2) one must require that the following condition be satisfied at $y = -1$:

$$\frac{d\psi}{dy} + \alpha\psi = 0. \tag{5}$$

The condition of nontriviality of the general solution of Eq. (2), written with the help of the conditions of attachment (3) and the condition (5), leads to a secular equation which, after its terms are estimated in order of magnitude $(\alpha \mathrm{Re}_n)^{-1/2}$, can be represented in the form

$$\frac{\begin{vmatrix} \dfrac{\psi_1(0)}{D\psi_1(-1)+\alpha\psi_1(-1)} & \dfrac{\psi_2(0)}{D\psi_2(-1)+\alpha\psi_2(-1)} \end{vmatrix}}{\begin{vmatrix} \dfrac{D\psi_1(0)}{D\psi_1(-1)+\alpha\psi_1(-1)} & \dfrac{D\psi_2(0)}{D\psi_2(-1)+\alpha\psi_2(-1)} \end{vmatrix}} = \frac{\psi_3(0)}{D\psi_3(0)}. \tag{6}$$

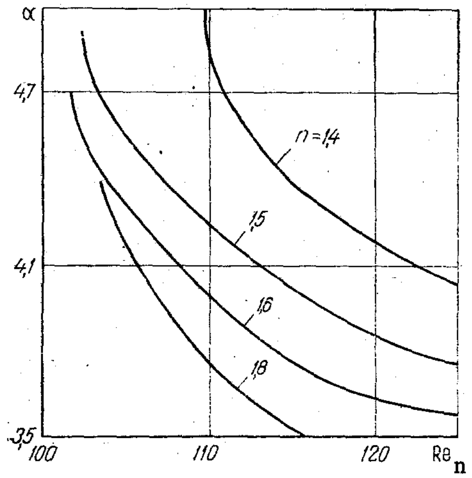

Fig. 1. Curves of neutral stability in the α, Re_n plane.

The solution of the secular equation (6) allows one to construct curves of neutral stability.

The curves of neutral stability in the α, Re_n plane constructed for the rheological numbers n = 1.4, 1.5, 1.6, and 1.8 are presented in Fig. 1. It is seen that the curves shift to the left with an increase in the number n. This is evidently connected with the flattening effect of the rheological number n on the velocity profile of the main flow.

NOTATION

U_0, velocity of plate motion; V_0, suction velocity; u(y), velocity profile of shear flow; n, k_n, rheological constants; L, characteristic size; ψ(y), amplitude of stream function; ψ(t, x, y), stream function; α, wave number; C, velocity of propagation of disturbances; D = d/dy, differential operator; ψ_i (i = 1, 2, 3), particular independent solutions of the equation of the Orr–Sommerfeld type; Re_n, generalized Reynolds number.

Dep. 1163-77, February 28, 1977.
Original article submitted October 12, 1976.

DISSIPATION HEAT FLUX FROM A CONDUCTING CONE TO A CONDUCTING PLANE

M. A. Gintsburg and Yu. N. Khromets

UDC 699.86:697.12/13

The following problem is solved. Two coaxial cones of thermally conducting material have different temperatures T_1 and T_2. Their apices coincide geometrically but are separated physically by an infinitely thin layer of ideal insulation, allowing the temperatures of the cones to be kept different. The heat flux from one cone to the other, the temperature distribution in the region between the cones, and their thermal resistance are found.

Such a problem has numerous applications. We can name some of them, such as the calculation of thermally conducting inclusions in layers of thermal insulation. When a layer is broken by a metal bolt to give the structure the required strength the bolt is usually insulated in order not to form a "cold bridge." One obtains a structure in the form of a conducting sheet with an opening through which the bolt passes, nowhere touching the walls (of thermal insulation). But the thermal resistance of such a system is by no means infinite: It is determined by the dissipation flux from the conducting sheet to the bolt (Fig. 1).

We replace the plane–bolt system with a system of two cones, one with a small aperture angle $\tan\theta_1 = \xi_1 \ll 1$, which approximates the bolt; and the other with an aperture angle $\tan\theta_2 = \xi_2 \gg 1$, which approximates the sheet.

This is the solution of the problem:

$$T = C_1 \ln \mathrm{tg}\,\frac{\theta}{2} + C_2 . \tag{1}$$

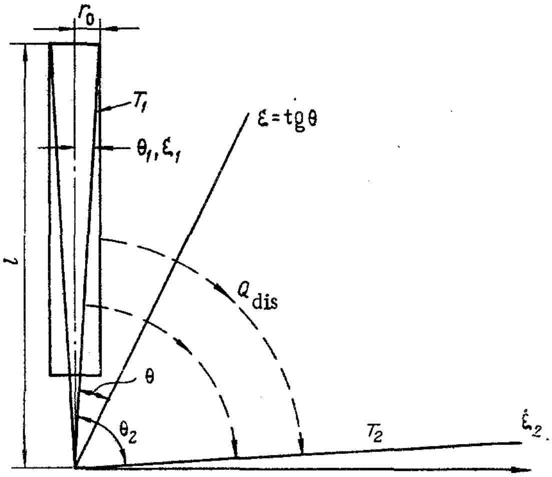

Fig. 1

The constants C_1 and C_2 are determined from the boundary conditions $T = T_1$ at $\xi = \xi_2 \ll 1$ and $T = T_2$ at $\xi = \xi_2 \gg 1$, i.e.,

$$C_1 = (T_1 - T_2)/A; \quad C_2 = \left(T_1 \ln \operatorname{tg} \frac{\theta_2}{2} - T_2 \ln \operatorname{tg} \frac{\theta_1}{2}\right) \Big/ A\ ; \quad A = \ln \operatorname{tg} \frac{\theta_1}{2} - \ln \operatorname{tg} \frac{\theta_2}{2}\ .$$

The lines of heat flow are circles with the center at the origin of coordinates. The total dissipation flux through the bolt of length l (taking $\xi_1 \ll 1$) is

$$Q_{dis} = 2\pi l \lambda (T_1 - T_2) \Big/ \left(\xi_1 \ln \frac{2}{\xi_1}\right),$$

and the thermal resistance is

$$R = \frac{1}{2\pi\lambda l}\, \xi_1 \ln \frac{2}{\xi_1}\ .$$

The solution (1) is easily generalized to the case of finite conductivity of the material of the cones $T = \sum\limits_n A_n P_n(\cos\theta) + B_n Q_n(\cos\theta)$ and to the nonlinear case when the heat capacity is $\lambda = \lambda_0[1 + \alpha(T - T_2)]$. Then

$$T = T_2 + \frac{1}{\alpha}\left[\sqrt{1 + 2\alpha\left(C_1 \ln \operatorname{tg} \frac{\theta}{2} + C_2\right)} - 1\right].$$

The constants A_n and B_n are determined from the boundary conditions.

Dep. 1159-77, March 5, 1977.
Original article submitted February 2, 1976.