ABSTRACTS OF PAPERS DEPOSITED AT VINITI*

ON THE ENERGY-SEPARATION EFFECT IN A GAS EJECTOR. II

A. A. Stolyarov UDC 621.4/6:533.697.5

We have discovered a new phenomenon in modes of energy separation in an axisymmetric ejector: rotation of the jet escaping from the nozzle and adhering to the wall of the mixing chamber. Such modes of ejector operation are identified with the escape of a jet into a long dead end (8-10 diameters).

It is shown that in contrast to the plane case, when the adherence of the jet is stable, the adherence of an axisymmetric jet is unstable. With the curving of a flooded jet the static pressure in a cross section of the jet will be unequal and unbalanced. The equalization of pressures over the cross section straightens the jet, after which it again curves spontaneously and adheres at another point, where the separation phenomenon is repeated.

In the paper an equation for the rotation frequency of an adhering jet is obtained from the assumption that in an axisymmetric ejector the jet escaping from the nozzle adheres to the wall of the mixing chamber and rotates in such a way that the static pressure gradient from the curvature of the jet is compensated by the static pressure gradient from its rotation in the cross section of the ejector.

The hypothesis was tested experimentally on an installation with an ejector which was described in [1]. We used TsTS-19 piezoelectric detectors with display of the signals on a dual-beam cathode-ray oscillograph. The detectors were placed on the wall of the mixing chamber (two detectors at a distance of 95 mm from the entrance) and on the face of the diaphragm (one detector) and were connected alternately to the oscillograph.

The experiments confirm the presence of adherence and rotation of the jet with a fundamental frequency of 143-1670 Hz.

It was discovered that complex transient phenomena develop in the ejector under some conditions. An oscillogram of a combination of vortical pulsations from the rotation of the jet, recorded at the wall of the mixing chamber (upper beam), and longitudinal acoustic vibrations, recorded near the diaphragm (lower beam), is shown in Fig. 1. Such modes, accompanied by a loud whistle, were excited at pressures of 37-46 bar at the nozzle inlet in an ejector with a shortened nozzle. With the original nozzle such a thing was not observed under any conditions. With a change in the pressure in the forechamber the frequency of the vortical pulsations is conserved while the frequency and shape of the acoustic vibrations change, being transformed into vortical pulsations and starting to spread out from the midline

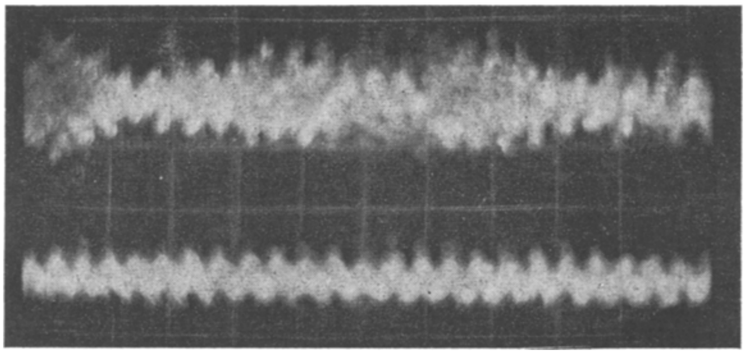

Fig. 1. Oscillogram of a combination of vortical pulsations and longitudinal acoustic vibrations.

*All-Union Institute of Scientific and Technical Information.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 34, No. 4, pp. 729-740, April, 1978.

0022-0841/78/3404-0495$07.50

of the signal. In the ejector with the original nozzle we observed a superposition of vortical pulsations and acoustic vibrations, synchronously recorded by all the detectors. The fundamental frequency of the acoustic vibrations was 1670-4000 Hz. We note that the signal amplitudes of the detectors are asymmetric relative to an increase and to a decrease of pressure in the forechamber (hysteresis phenomena).

The effect of energy separation in a gas ejector most likely has a vortical nature, although acoustic vibrations may also exert a certain influence. The point of adherence of the jet is connected with the ratio of the pressures in the forechamber and at the diaphragm. With a decrease in pressure in the forechamber the jet adheres closer to the entrance to the mixing chamber, while with an increase in pressure the point of adherence moves toward the diaphragm. In the experiments the movement of the point of adherence of the jet along the ejector was accompanied by an increase in the signal amplitude of the detector on the wall and a decrease in the signal amplitude of the detector on the diaphragm with a decrease in the pressure in the forechamber. An increase in the pressure in the forechamber led to the opposite. A cooled zone of return vortical flows lies in the region of adherence of the jet. Therefore, in the first case the cooled gas escapes into the forechamber while in the second case it escapes through the diaphragm. The rotation of the gas at the exit from the diaphragm is also revealed by the fact that the cooling effect of the diaphragm decreased even with supercritical pressure drops at it [1].

LITERATURE CITED

1. A. A. Stolyarov, "On the energy-separation effect in a gas ejector," Inzh.-Fiz. Zh., 31, No. 6 (1976).

Dep. 3975-77, August 24, 1977.
Original article submitted December 23, 1976.

TIME OF THE TRANSITIONAL PROCESS DURING THE TURNING ON OF AN INCOMPRESSIBLE VISCOUS LIQUID INTO A PIPELINE WITH A LOCAL RESISTANCE

G. G. Zel'kin

UDC 532.5

The turning on of an incompressible viscous liquid under constant pressure from a reservoir through a throttle washer into an unfilled pipeline with rigid walls is analyzed. The process of establishment of the flow in the pipe is studied to determine the dependence of the time of the transitional process on the energy supplied and the energy expended on overcoming the hydraulic resistances.

Tests were conducted on a circulating stand [1] to clarify the mechanism of the nonsteady motion. The tests confirmed a fact established earlier [2]: In a local resistance during the nonsteady motion vortical flow is induced which disappears when the motion becomes steady. The induction of vortical flow in a local resistance is due to the viscosity. Motion pictures of the tests showed the helical character of the flow.

Thus, two vortical flows must be considered in the nonsteady motion: one which is also retained in the steady motion and a second which is induced in a local resistance during the nonsteady motion and disappears when the motion becomes steady. Taking the flows as helical, and therefore as proportional to the velocity in the direction of the pipe axis, we obtain a functional dependence for the vortex:

$$\Omega(t) = \sqrt{\beta_1 + \beta_2 \frac{d^2 l}{dt^2}} \cdot \frac{dl}{dt}. \tag{1}$$

With allowance for it we obtain from the Navier–Stokes equations an expression for the time of the transitional process:

$$t_t = \frac{1}{\beta_1}\left[\frac{3}{\nu}(1 + K\alpha^2) + \frac{\nu\beta_2^2(P_0 - p_0)}{2\rho(1 + K\alpha^2)^2} + \frac{7}{4}\beta_2\sqrt{\frac{2(P_0 - p_0)}{\rho(1 + K\alpha^2)}}\right], \tag{2}$$

where P_0 and p_0 are the pressure at the free surface of the reservoir and the atmospheric pressure; ρ is the density of the liquid; ν is the coefficient of kinematic viscosity; K, β_1, and β_2 are proportionality constants; $\alpha = (R/r_0)^2$; R and r_0 are the radii of the pipeline and of the opening in the throttle washer.

The increase in t_t with an increase in α which follows from the equation found experimental confirmation in the tests with six throttle washers whose coefficients of resistance are $\zeta_{t.w} = 0.4$, 1.0, 2.0, 4.2, 8.0, and 18 and with liquids of different densities $\rho = 0.8$, 1.2, 1.25, 1.4, and 2.2 g/cm³. This relationship does not correspond to the results of calculations obtained from the basic equation for the nonsteady motion, in which the vortical flow induced in the local resistance is not taken into account.

The mechanism being considered for the nonsteady motion made it possible to find an engineering solution to the problem in accordance with which the time of the transitional process has the form [3]

$$t_t = \frac{L_v + L_i}{R_h}, \tag{3}$$

where L_v and L_i are the coefficients of vortical induction and inertia and R_h is a quantity which determines the active hydraulic resistances [4].

Equation (3) received confirmation in tests with pipes of different lengths but with the same local resistances. Dependences $L_v/L_i = f(\zeta_{t.w})$ determining the ratio of the corresponding energy expenditures were constructed from the test data. It turned out that the energy expenditures on vortex formation are several times greater than those on overcoming the inertia of the liquid.

A direct correlation between L_v and the coefficients of resistance of the throttle washers was established from the test data. Such a connection was also established with the coefficient of resistance of the valve. This made it possible to develop a method for calculating a number of problems in the transitional processes in pipes with local resistances [5].

LITERATURE CITED

1. G. G. Zel'kin, "Vortical flows behind a local resistance during nonsteady motion in a circulating stand," Abstracts of Reports to Eleventh Scientific – Technical Conference of the All-Union Correspondence Engineering–Construction Institute [in Russian], Moscow (1976).
2. G. G. Zel'kin, "The phenomenon of hydraulic induction during the nonsteady motion of an incompressible viscous liquid," Inzh.-Fiz. Zh., 21, No. 6 (1971).
3. G. G. Zel'kin, "A new equation for the nonsteady motion of an incompressible viscous liquid," in: Proceedings of Third All-Union Conference on Applied Aerodynamics [in Russian], Vol. 1, Kiev (1973).
4. G. G. Zel'kin, "On the nature of hydraulic resistances based on the results of studies of transitional processes," in: Proceedings of Eleventh Congress of the Moscow Aerohydrodynamics Institute [in Russian], Vol. 6, Leningrad (1965).
5. G. G. Zel'kin, "Calculation of pressurized hydraulic systems with local resistances during nonsteady motion of an incompressible viscous liquid," Abstracts of Reports to Tenth Scientific–Technical Conference of the All-Union Correspondence Engineering–Construction Institute [in Russian], Part 1, Moscow (1974).

Dep. 4076-77, September 12, 1977.
Original article submitted March 14, 1977.

PROPERTIES OF HEAT EXCHANGE AT THE FREEZING BOUNDARY OF A LAYER OF ICE AND CONCRETE UNDER THE ACTION OF RADIATION

A. A. Mogutnov

UDC 536.421.4:536.3

The properties of the heat exchange at the freezing boundary of an ice layer with a substrate at low values of the Fourier number (Fo) are studied in the article.

The problem of finding the nonsteady temperature field in a composite solid consisting of an ice layer and a semibounded concrete substrate is stated mathematically for monochromatic radiation. In this case there is an internal heat source in the ice layer consisting of the radiation absorbed volumetrically by the ice.

An exact solution of this problem is presented which shows the temperature variation at the contact boundary between the ice and concrete and an approximate solution is presented which approximates the exact solution within restricted limits of variation of the Fourier and Bouguer (Bu) numbers.

Through an analysis of the solution it is shown that at low Fourier numbers local heating of thin layers of ice and concrete at the contact boundary is provided, with a decrease in Fo leading to a decrease in the energy expenditures on ice heating at the contact boundary up to the melting temperature. The influence of the Bouguer number on the energy expenditures in heating the solids at the contact boundary is also analyzed.

Some properties of the process of ice heating at the contact boundary with concrete by thermal radiation were obtained experimentally. A radiator built on the basis of quartz halide lamps was used to create the flux of thermal radiation. A sheet thermocouple 10 μm thick was used to measure the nonsteady temperature at the contact boundary of the ice layer and the concrete. The results of theoretical and experimental estimates of the thermal inertia of such a thermocouple are presented.

The experimental studies are represented in the form of dependences $Ki \cdot Fo = f(Ki)$ (Ki is the Kirpichev number). With an increase in Ki to 0.45 for glassy ice the experimental points are satisfactorily approximated by the theoretical curve for monochromatic radiation with $Bu = 0.5$.

Dep. 4075-77, September 9, 1977.
Original article submitted May 30, 1977.

PECULIARITIES OF THE PROCESS OF CONDENSATION OF FILMS OF BOROSILICATE GLASS IN THE CASE OF HETEROGENEOUS REACTIONS ON THE CONDENSING SURFACE

Yu. Z. Bubnov and L. N. Vishevnik

UDC 536.422

In the analysis of the basic laws of the vaporization, mass transfer, and condensation of the vapors of semiconducting and dielectric compounds it has been assumed that the interaction of the moving vapor is connected only with the condensation and revaporization of the particles [1, 2]. However, in a number of cases, such as in the fabrication of multilayered systems, the films precipitated in the process of condensation can interact chemically with the underlying layers, altering in the process such characteristics as the coefficient of condensation, the rate of growth of the condensate, etc.

Some peculiarities of the process of condensation of films of borosilicate glass (BSG) in the technology of the fabrication of integrated circuits are discussed in the present paper. In this case the BSG is deposited onto structures whose individual components (Si, SiO_2, Mo) interact chemically with it to one degree or another.

The BSG was deposited in a quasiclosed volume consisting of a detachable cylindrical chamber placed under the bell of a vacuum installation, and the resulting rate of condensation w^* was studied as a function of the x coordinate directed along the generatrix of the chamber.

In the case of a chemical interaction between the moving vapor and the condensing surface a change in the critical condensation temperature T_{cr} in comparison with condensation onto an inert substrate is characteristic.

For the substrates which we considered (Si, SiO_2, Mo) a critical condensation cross section is entirely absent (in contrast to Policor, which is inert with respect to BSG vapor), since the chemical reactions leading to the formation of a layer on the condensing surface are also possible when $T > T_{cr}$. The resulting condensation rate in the initial section of the chamber, i.e., with the substrate temperature equal to the temperature of the BSG surface being vaporized, can characterize the chemical activity of the substrate material with respect to the moving vapor. The values of the chemical activity of S, SiO_2, and Mo thus determined are in agreement with thermodynamic calculations of the corresponding reactions of the substrate materials with borosilicate glass. As the temperature of the condensing surface decreases the profiles $w^* = w^*(x)$ differ slightly, which may be connected with a decrease in the coefficients of diffusion of the components regulating the chemical reaction rates and, as a consequence, with a decrease in the influence of the factor of chemical interaction between the moving vapor and the substrate on the growth rate of the condensate.

On the basis of the analysis carried out in the paper a number of practical conclusions are drawn which must be taken into account when using vitreous films in the technology of integrated circuits.

LITERATURE CITED

1. Yu. Z. Bubnov, M. S. Lur'e, M. N. Libensov, V. S. Ravin, and G. A. Filaretov, Inzh.-Fiz. Zh., 21, No. 4 (1971).
2. Yu. Z. Bubnov, M. S. Lur'e, G. A. Filaretov, and L. N. Shendler, Inzh.-Fiz. Zh., 25, No. 4 (1973).

Dep. 3972-77, May 4, 1977.
Original article submitted August 12, 1976.

SOLUTION OF LINEAR STOCHASTIC PARABOLIC EQUATIONS BY THE DECOMPOSITION METHOD

R. N. Shvets and V. I. Eleiko

UDC 536.12

Let us consider an inhomogeneous linear parabolic equation with independent instantaneous random sources W in a region V of n-dimensional space bounded by the hyperplanes S_n:

$$\partial u/\partial \tau = L_n u + W, \quad P_n \in V, \quad -\infty < \tau < \infty. \tag{1}$$

At the boundary S_n of region V the function u satisfies the boundary conditions

$$Mu = f, \quad P_n \in S_n, \quad -\infty < \tau < \infty. \tag{2}$$

Here L_n and M are linear determinate differential operators and f is a stochastic function of the coordinates and time.

On the assumption that the random functions W and f are representable in the canonical forms

$$W = \sum_j \xi_j \varphi_j (P_n, \tau), \quad f = \sum_j \xi_j \psi_j (P_n, \tau),$$

to solve the stochastic boundary problem (1), (2) we use the method of canonical expansion [1, 2]

$$u = \sum_j \xi_j v_j (P_n, \tau),$$

where ξ_j are independent random quantities and φ_j, ψ_j, v_j are determinate functions of the coordinates and time.

Furthermore, we assume that the conditions of the decomposition theorem [3] are satisfied for the nonrandom functions v_j. Then the deterministic solution of our problem is represented in the form of a product of orthogonal solutions

$$v_j (P_n, \tau) = v_{jm} (P_m, \tau) v_{jk} (P_k, \tau) \quad (m + k = n),$$

to find which we obtain two simpler equations

$$(\partial/\partial \tau - L_m) v_{jm} (P_m, \tau) = \varphi_{jm} (P_m) \delta (\tau);$$

$$(\partial/\partial \tau - L_k) v_{jk} (P_k, \tau) = \varphi_{jk} (P_k) \delta (\tau),$$

each of which describes independent m-dimensional and k-dimensional processes in n-dimensional space, assigned by the instantaneous sources $\varphi_{jm}\delta(\tau)$ and $\varphi_{jk}\delta(\tau)$.

On the basis of the canonical representation of the random function $u(P_n, \tau)$ its probability characteristics are determined.

An example is discussed.

LITERATURE CITED

1. V. V. Bolotin, Statistical Methods in Construction Mechanics [in Russian], Stroiizdat, Moscow (1965).
2. V. S. Pugachev, The Theory of Random Functions [in Russian], Fizmatgiz, Moscow (1962).
3. N. N. Rykalin, Dokl. Akad. Nauk SSSR, 125, No. 3 (1959).

Dep. 3976-77, August 26, 1977.
Original article submitted December 20, 1976.

A NUMERICAL SOLUTION OF THE HEAT-CONDUCTION PROBLEM
FOR A CYLINDRICAL ROD WITH A CONICAL END

E. I. Rozovskii, A. I. Mitin,
and S. P. Reshenov

UDC 536.24.02

In the solution of problems connected with the analysis of the thermal conditions of the electrodes of high-pressure arcs it is required to determine the power removed from the cathode spot due to the heat conduction of the electrode. In a number of cases it is also required to know the temperature distribution in the volume of the electrode, which consists of a cylinder with the end in the form of a truncated cone. Here, in the majority of real cases, one can neglect the release of power in the volume and assume that the removal of heat from the lateral surface of the electrode is accomplished only through the thermal emission of the electrode material.

To find the temperature field in the volume of the electrode one must solve the Poisson equation with the following boundary conditions: In the central part of the small base of the truncated cone the value of the function T_c is assigned, while the value of the normal derivative, which is a nonlinear function of the temperature and in the general case depends explicitly on the coordinates of the point of the surface, is assigned on the rest of the surface. The problem was solved with the help of the implicit iteration method of variable directions (the longitudinal–transverse difference system of establishment). The difference system approximates the original problem with the order $o(|h_{i+1} - h_i| + h_i^2)$, where h_i is a step of the difference system. As for the stability of the system, a test showed that it is stable only with a certain ratio of iteration parameters, presented in the article, in which the criterion allowing one to consider the solution obtained for the difference problem as coinciding with the solution of the original problem is also indicated. Expressions are presented for the assignment of the initial approximation providing the maximum rate of convergence of the problem, and the results of a calculation of the power removed from the central part of the small base of the truncated cone through heat conduction are presented for a semi-infinite tungsten electrode in the following range of variation of the parameters: T_c = 2600, 2900, and 3000°K; radius of cylindrical part of the electrode y_1 = 0.001, 0.003, and 0.005 m; radius of smaller base of the truncated cone $y_0 = (0.2, 0.6, 1.0) \cdot y_1$; radius of central part of the smaller base of the truncated cone (in which the value of T_c is assigned) – $0 \leq y_c \leq y_0$. The angle at the apex of the truncated cone is 90°.

Dep. 3974-77, August 23, 1977.
Original article submitted April 12, 1977.

QUASISTEADY MODE OF HEAT CONDUCTION IN A ROD WITH BOUNDARY CONDITIONS OF THE FIRST KIND

B. A. Kirichenko

UDC 536.12

The case of a one-dimensional nonsteady equation of heat conduction without internal heat sources is considered for a rod thermally insulated along the lateral surface and with thermophysical characteristics which do not depend on the temperature. The boundary conditions at the ends of the rod are assigned in the form of temperatures with an arbitrary time dependence. These dependences are expressed through the rate of change $\theta = dT/dt$ of the temperature and are henceforth used in such a form. The concept of the quasisteadiness criterion is introduced, which represents the relative departure of the solution of the nonsteady heat-conduction problem from the corresponding steady solution. Quasisteadiness is defined as smallness of this ratio in comparison with unity. The general solution of this boundary problem is used to analyze processes of heat conduction in a rod to reveal quasisteadiness, which is connected with the resolution of two questions: 1) Can a process be quasisteady in principle? 2) in what time interval can this process be referred to as quasisteady? The analysis is built on the fact that the temperature field in a rod is uniquely determined by the quantities θ at its ends, and the latter are approximated by piecewise-linear functions, which allows one to represent the general solution in the form of simple functions suitable for practical application. Three of the simplest cases of the approximation of the dependence $T(t)$ at each end of the rod by two linear sections with different slopes, which are important in a practical respect, are considered in detail. In two of the cases the first linear section has an essentially nonsteady character. For these two cases approximate equations are derived for estimating the time of establishment of the presumed quasisteady state in the second linear section. The course of analysis is outlined for more general approximating temperature profiles through the application of the equations already obtained. In addition, a simplified approximate equation is derived for calculating the quasisteadiness criterion in the case of sufficiently smooth time functions of the temperatures at the rod boundaries which allows one, with minimal time expenditures, to estimate the applicability of the quasisteadiness concept to heat-conduction processes in a rod. This same equation can serve as a means of quick estimation of the quasisteadiness for all other cases.

Dep. 3476-77, August 8, 1977.
Original article submitted August 30, 1976.

DETERMINATION OF HEAT FLUX IN A TURBULENT BOUNDARY LAYER WITH GAS INJECTION AND A PRESSURE GRADIENT

A. S. Kondrat'ev

UDC 536.244

An expression for the instantaneous velocity and temperature profiles in a turbulent boundary layer at a permeable surface with a pressure gradient is obtained using a model of penetration and restoration. The profiles of average quantities are determined using a distribution function of the time of instantaneous contact, assigned in the form of a random function. On the basis of the expressions for the averaged quantities an equation is obtained for the local average Stanton number (St)

$$\mathrm{St}=\left\{\frac{1}{4}\left(\frac{v_w}{u_\infty}\right)^2+\left(\frac{c_f}{2}\right)^2\mathrm{Pr}^{-1}\left\{\left[\left(1+\frac{v_w}{u_\infty}\cdot\frac{1}{c_f/2}\right)-\frac{2k}{(c_f/2)^2}+\sqrt{\left(1+\frac{v_w}{u_\infty}\cdot\frac{1}{c_f/2}\right)^2-\frac{4k}{(c_f/2)^2}}\right]\right\}2^{-1}\right\}^{\frac{1}{2}}-\frac{1}{2}\frac{v_w}{u_\infty}$$

as a function of the Prandtl number (Pr), the dimensionless injection velocity v_w/u_∞, the coefficient of friction c_f, and the dimensionless pressure gradient

$$k=(\nu/u_\infty{}^2)\frac{du_\infty}{dx}.$$

The Reynolds similarity coefficient in the presence of a pressure gradient at an impermeable surface and in the presence of injection with a zero pressure gradient is calculated using the equation obtained. The results of the calculations are in satisfactory agreement with the experimental data available in the literature. The calculated ratio of the heat flux with injection to the heat flux without injection also agrees satisfactorily with the experimental data.

Dep. 3475-77, August 1, 1977.
Original article submitted June 3, 1976.

MASS TRANSFER IN A JET ESCAPING INTO A FLUIDIZED BED

N. A. Shakhova* and V. K. Lukashev

UDC 66.096.5

The results of a study of mass transfer in jets escaping into a fluidized bed and whose impulse is sufficient to form a gas tongue (a gas cavity with an insignificant particle content) are presented in the paper. In this case the particles entrained by the jet move predominantly along the boundary of the gas tongue, forming a two-phase boundary zone.

The experimental study of mass transfer in the indicated system was conducted in a fluidized bed of inert and adsorbing materials on a specially developed installation. The installation had an apparatus 263 mm in diameter; an interchangeable nozzle (d_0 = 2, 4, 6, 8 mm) was located at the center of its gas-distribution grid. A mixture of air and carbon dioxide, the concentration field of which was measured by the sampling method with analysis on a chromatograph, was fed through the nozzle.

As a result of the experimental study it was established that under the conditions of inert material the intensity of the decline in CO_2 concentration along the length of the jet is not uniform. The main decline in concentration occurs within the gas tongue. On the whole, the gas mixing in a jet escaping into a fluidized bed is less than that in an empty apparatus. Intensive radial gas filtration occurs from the jet into the bed, as a result of which the concentration thickness of the jet considerably exceeds the dynamic thickness. It was established that the intensity of mass transfer increases with an increase in the discharge velocity and the particle diameter and with a decrease in the nozzle diameter and the

*Deceased.

fluidization number. The use of adsorbing particles as the solid material leads to an increase in the intensity of mass transfer in the jet in comparison with an inert material owing to the transfer of an additional amount of CO_2 into the bed by the solid particles. The dynamic and concentration boundaries are close in this case.

An analysis of the experimental curves of variation in the concentration in cross sections of the jet in dimensionless coordinates showed their affinity for both the adsorbing and the inert materials. The concentration profiles obtained are approximated by the corresponding equations.

The experimental data on the variation in concentration along the jet axis were generalized on the basis of the integral equation of conservation of the transferred matter in cross sections of the jet. The functions obtained allow one to calculate the concentration field of a gas component in a jet escaping into a fluidized bed of inert material. The values of the concentration boundary of the jet and the concentration at the boundary of the gas tongue required for this are determined from empirical equations.

Dep. 3474-77, July 28, 1977.
Original article submitted October 14, 1976.

SOLUTION OF AXISYMMETRIC PROBLEMS OF STEADY HEAT CONDUCTION IN COMPOSITE IMPERFECTLY CONJUGATED REGIONS WITH ARBITRARY BOUNDARY CONDITIONS

A. M. Makarov and V. R. Romanovskii UDC 536.24

Studies of steady temperature fields in axisymmetric composite regions with conditions of imperfect thermal contact at the conjugation surfaces are of interest for practical applications in power engineering, thermal strength, etc.

A steady axisymmetric temperature distribution in piecewise-orthotropic thermally insulating cylinders having an arbitrary number of conjugation surfaces is constructed using the method of finite integral transformation modified by the authors of the paper for the solution of imperfectly conjugate boundary problems. Radial and end conjugation of the cylindrical bodies of finite size which are in contact are analyzed. Boundary conditions of the third kind with variable coefficients are adopted as the boundary conditions at the surfaces orthogonal to the conjugation surfaces.

The Sturm-Liouville problems for the determination of the kernels of the integral transformations are analyzed in the paper and their solutions are constructed; a finite integral transformation is performed along the coordinate orthogonal to the conjugation surfaces; infinite systems of linear algebraic equations are obtained for the coefficients in the general solution in transform space and the reduction method is used for their solution.

The results are illustrated by examples of numerical calculations.

The finite integral transformation in problems with variable coefficients in the boundary conditions was earlier considered impracticable [1, 2]. The results obtained considerably broaden the region of applicability of the method of finite integral transformations.

LITERATURE CITED

1. A. V. Lykov, Izv. Akad. Nauk SSSR, Énerg. Transp., No. 2 (1969).
2. I. A. Zaideman, B. V. Ivanov, V. A. Korobov, and Yu. L. Khavkin, Teplofiz. Vys. Temp., 14, No. 3 (1976).

Dep. 4073-77, September 26, 1977.
Original article submitted April 15, 1977.

ON THE DETERMINATION OF THE OPTIMUM DISTRIBUTION OF FUEL DELIVERY TO HEATING FURNACES

A. S. Nevskii

UDC 621.783.2

The problem of the optimum time distribution of the fuel delivery to a periodically operating heating furnace is solved by the variational method. It is shown that this solution can also be applied to a number of other engineering problems.

The total heat consumption during a heating period is

$$\bar{Q}_h = \int_0^{\tau_0} Q_h d\tau = G \int_{T_{ms}}^{T_{me}} Q_h Q_{tr}^{-1} c_m dT_m, \tag{1}$$

where $d\tau = Gc_m Q_{tr}^{-1} dT_m$ and the heating time is

$$\tau_0 = \int_{T_{ms}}^{T_{me}} Gc_m Q_{tr}^{-1}\, dT_m. \tag{2}$$

We determine the minimum of (1) for a given (2). In accordance with the rules of variational calculus, we set up the function $F = Q_h Q_{tr}^{-1} + KQ_{tr}^{-1}$ and equate its derivative with respect to Q_h to zero.

The following condition is obtained:

$$Q_{tr} / Q'_{tr} - Q_h = K = \text{const.} \tag{3}$$

The solution obtained is interpreted by the scheme shown in Fig. 1, set up in application to the concrete conditions of the example under consideration. Curves 1 and 2 represent the dependences of Q_{tr} on Q_h for different temperatures of the material. The optimum values of these quantities are obtained at the points of tangency of the straight lines drawn from the point A lying on the abscissa at a distance K from the zero point.

To solve the problem one must know the dependence of Q_{tr} on Q_h. Such a dependence is obtained from the joint solution of the equations of balance and of heat transfer:

$$Q_{tr} = Q_h w (T_t - T_d), \tag{4}$$

$$Q_{tr} = H\sigma_i [T_t^{4(1-n)} T_d^{4n} - T_s^4]. \tag{5}$$

These equations are sufficient for the solution of a problem with a thermally thin body. For a massive body we use the following approximation equation in addition:

$$T_s - T_m = Q_{tr} R / H\lambda k_1. \tag{6}$$

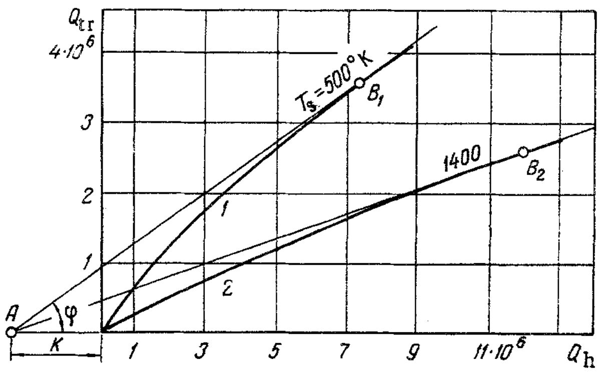

Fig. 1. Scheme for determination of the optimum fuel distribution. Q_{tr}, W; Q_h, W.

As a result of the solution of the equations for n = 1 we obtain the following expression for the determination of the optimum temperature of the departing gases:

$$\frac{(\theta_d^4-\theta_s^4)^2}{\theta_d^3(1-\theta_d)^2}\left(1+4\theta_s^3\frac{\mathrm{Sk}}{K_1}\right)=\frac{4Kw}{\sigma_i HT_t^3}=K_0. \qquad (7)$$

Equations (4)-(7) allow one to determine the optimum heat loads during the heating of the metal.

An analogous solution is also obtained for continuous sectioned furnaces. Only in periodically operating furnaces is the fuel consumption referred to a moment of time; here it is referred to a unit of heating surface. The sizes of the heating surface in the latter problem took the role of the time in the problem of periodically operating furnaces.

NOTATION

G, weight of a charge of metal; Q_h, consumption of fuel heat per unit time; $\bar{Q}_h$, total heat consumption during heating; Q_{tr}, heat transfer to metal per unit time; H, size of heating surface; T_m, T_s, T_t, T_d, absolute temperatures: average for metal, of heating surface, theoretical, and of departing gases; $\theta_d = T_d/T_t$; $\theta_s = T_s/T_t$; τ, time; τ_0, heating time; c_m, heat capacity of metal; λ, coefficient of thermal conductivity of metal; w, water equivalent of combustion products; R, characteristic size of body being heated; k_1, coefficient ($k_1 = 4$ for a cylinder, 6 for a slab); $\mathrm{Sk} = \sigma_i RT_t^3/\lambda$, Stark number.

Dep. 3973-77, August 15, 1977.
Original article submitted October 28, 1976.

ON THE PERMEABILITY FACTOR IN ESTIMATING THE INFLUENCE OF FREE CONVECTION ON HEAT EXCHANGE IN THE BED OF A FREE-FLOWING SYSTEM

I. Ya. Neusikhin and V. V. Pokotilov

UDC 624.433

During free convection in beds of large-size charges, which include construction charges, a significant role is played by the layer near the wall, the porosity Π_b, and the permeability $\varkappa_b$, which are not constant over its depth and are higher than the integral values for the main average bed. In the paper an attempt is made to establish the influence of the boundary layer on the overall permeability of a free-flowing system and to establish its thickness in order to more soundly determine the permeability factor in the Darcy number (Da) [1].

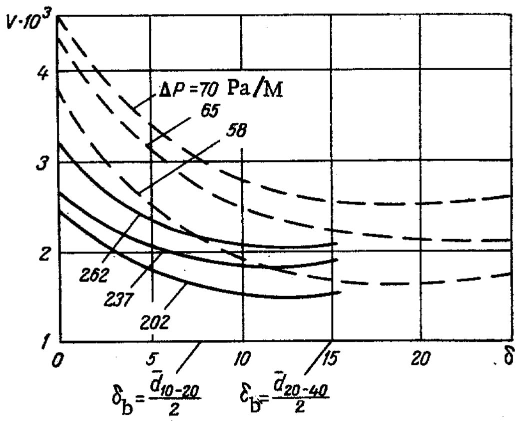

Fig. 1. Integral airflow rates. V, m³/sec; δ, mm.

The experimental studies were conducted in a mode of Darcy filtration in gravel construction materials with fractional compositions of 5-10, 10-20, and 20-40 mm. The experimental installation consisted of the following main elements: a vertical column of square cross section, an air blower, and measuring instruments.

An instrument consisting of a vane anemometer and a square diffusor was used to determine the thickness of the boundary layer. The integral airflow rates at different distances from the column walls were measured by mounting the diffusor at the surface of the charge (air movement upward from below). Characteristic functions for gravels with fractional compositions of 10-20 and 20-40 mm are presented in Fig. 1.

The results obtained allow one to conclude that it is preferable to take the thickness of the boundary layer as equal to half the mean diameter of the fraction: $\delta_b = \bar{d}/2$.

The permeabilities $\varkappa_a$ and $\varkappa_b$ of the average bed and the boundary layer were determined by two methods. In both cases, taking $\delta_b = \bar{d}/2$, we set up systems of equations of flow-rate balance, through the solution of which we obtained the following experimental functions:

$$\bar{\gamma} = \varkappa_b/\varkappa_a \simeq 4.0, \tag{1}$$

$$\varkappa_a = 8.53\ \bar{d}^2 \cdot 10^{-11}, \tag{2}$$

$$\varkappa_b = 34.1\ \bar{d}^2 \cdot 10^{-11}. \tag{3}$$

Allowing for the character of the convective motions of a dispersion medium in horizontal beds [2], it is desirable to take the volume average of the permeability of the charge as the calculating permeability:

$$\bar{\varkappa} = [V_a \varkappa_a + (V_0 - V_a)\, \varkappa_b]/V_0. \tag{4}$$

LITERATURE CITED

1. M. Combarnous and S. Bories, Int. J. Heat Mass Transfer, 17 (1974).
2. M. Hirata, N. Nishiwaki, M. Ito, and H. Miyashita, in: Heat and Mass Transfer [Russian translation], Vol. 9, Nauka i Tekhnika (1968).

Dep. 4074, September 26, 1977.
Original article submitted January 21, 1977.