ABSTRACTS

EXPERIMENTAL RESEARCH ON THE THERMAL CONDUCTIVITY OF n-HEPTANE

Yu. L. Rastorguev and V. V. Pugach

UDC 536.222

The thermal conductivity of paraffin hydrocarbons, especially n-heptane at high pressures, has been little studied. Data are given in the literature about the thermal conductivity of n-heptane at pressures up to 50 MN/m^2 [1-2].

The present work gives the results of experimental research on the thermal conductivity of n-heptane at pressures up to 150 MN/m^2 and in the temperature range 20-180°C. The measurements were carried out by a method of coaxial cylinders on an apparatus described in [3]. The maximum relative error of measurement of the thermal conductivity was ±1.6%.

In the experiments n-heptane of the quality "standard" ($\rho_4^{20} = 0.6838$; $n_D^{20} = 1.3877$) was used. The thermal conductivity was measured isothermally over the range ~20-30 MN/m^2. The experimental data obtained are tabulated. Analysis of the experimental data obtained showed that with increases of temperature the influence of pressure on the thermal conductivity increases, as a result of which the temperature coefficient of the thermal conductivity of n-heptane decreases and tends towards 0. This circumstance makes it possible to find theoretically the approximate pressure at which the temperature coefficient of the thermal conductivity of n-heptane changes its sign. In the work the temperature dependences of $(\partial\lambda/\partial p)_t^{cp}$ were determined for that region of pressures (0.098-50 MN/m^2) in which the effect of pressure is greatest. The data derived from [1-2] are given for comparison. The nature of the variation $(\partial\lambda/\partial p)_t^{cp}$ with increase in temperature is approximately the same for all investigators; with increase of temperature the pressure effect increases, but the influence of the temperature on the pressure effect according to the data of [1] is less than in the present work and in [2]. The article also gives graphs which reflect these relationships. As a result of treatment of the experimental material we have obtained an interpolation equation for the thermal conductivity of n-heptane

$$\lambda_{p,t} = \lambda_{p,20} - \left(\frac{\partial\lambda}{\partial t}\right)_p^{c_p} \cdot (t-20),$$

where

$$\lambda_{p,20} = \lambda_{20} + 0.0533 \ln\left(1 + \frac{p}{101{,}45}\right),$$

$$\left(\frac{\partial\lambda}{\partial t}\right)_p^{c_p} = \left(210 - 0.5p + 10^{1.702-0.035p}\right) \cdot 10^{-5}.$$

The discrepancies between the experimental data and the calculated data do not exceed the experimental errors.

The problems of the influence of radiation on heat transfer by molecular thermal conductivity are also discussed in the work. The article also gives smoothed data in tabulated form.

LITERATURE CITED

1. I. F. Golubev and Ya. M. Naziev, Tr. Énergeticheskogo Instituta Akad. Nauk AzSSR, 15 (1961).
2. Yu. L. Rastorguev, G. F. Bogatov, and B. A. Grigor'ev, Izv. Vuzov, Neft' i Gaz, No. 12, 59 (1968).
3. Yu. L. Rastorguev and V. V. Pugach, Teploénergetika, No. 4 (1970).

Petroleum Institute, Groznyi. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 345-346, August, 1970. Original article submitted August 25, 1969; revision submitted March 23, 1970.

RESEARCH ON THE THERMAL CONDUCTIVITY OF CAST CERAMICS IN RELATION TO ITS STRUCTURE AND TEMPERATURE

I. I. Bykov and F. F. Lezhenin

UDC 536.21

Research is carried out on the coefficient of thermal conductivity of four kinds of cast ceramics of different chemical and mineral composition (Table 1), which are characterized by the predominance of formations of monoclinic pyroxene of varying composition in coalescence with the vitreous phase.

Investigations in the temperature range 200-1000°C were carried out on a special vacuum apparatus with a separate circuit for supply of the heater by using thermocouples in a specimen of diameter 25 mm and height 150 mm for steady-state systems by means of initial heating in stages.

The experimental data were treated by a method of least squares with a view to obtaining a functional relationship in the temperature range 200-1000°C in the form

$$\lambda = a + bt,$$

where the values a and b respectively for the following cast materials are: basalt–hornblendite 0.88 and $3.88 \cdot 10^{-4}$, diabase 1.09 and $1.55 \cdot 10^{-4}$, granite–slag 1.12 and $3.5 \cdot 10^{-4}$, and wollastonite–pyroxene 0.9 and $5.5 \cdot 10^{-4}$. The deviation of the experimental data from the values derived from the equations is 10-12%.

TABLE 1. Chemical and Mineral Composition of the Investigated Material

No.	Cast mineral	Content of the charge, wt. %	Chemical composition, mass %										Phase and mineral composition of the casting
			SiO_2	Al_2O_3	Fe_2O_3	FeO	TiO_2	CaO	MgO	MnO	Cr_2O_3	R_2O	
1	Basalt – homblendite	Basalt, 90. Hornblendite, 10. Chromite (above 100%), 2	47,2	12,5	6,2	7,1	1,5	9,1	8,3	0,4	1,2	2,5	Monoclinic pyroxene of augitic composition in coalescence with glass, 80%; magnetite, 3-5 %, free glass, 15%; separate grains of chromite.
2	Diabase	Diabase, 100. Chromite (above 100%), 2	49,4	11,0	8,1	7,6	2,5	8,4	6,5	—	0,6	2,5	Monoclinic pyroxene of augitic composition in coalescence with glass, 60-65%; magnetite, 15-20 %; free glass, 15-20%; separate grains of chromite.
3	Granite – slag	Granite, 45, Blast furnace slag 55. Chrome – magnesite (above 100%), 3	44,5	8,7	1,0	2,2	—	24,5	8,9	—	4,9	4,5	Monoclinic pyroxene of diopside –jadeite composition, 60-70%; free glass, 30-40%; grains of chromite, up to 5%.
4	Wollastonite – pyroxene	Blast furnace slag, 50. Perovskite concentrate 25. Quartz sand, 25.	47,1	2,6	1,3	1,3	8,6	30,1	6,7	1,5	—	1,2	Fibrous formation of wollastonite 60-65%; skeleton formations of monoclinic pyroxene, 30%; separate star-shaped formations of wollastonite; free glass, 5-10%

Institute of Casting Problems, Academy of Sciences of the Ukrainian SSR, Kiev. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 347-349, August, 1970. Original article submitted June 18, 1969; revision submitted March 23, 1970.

The thermal conductivity of cast ceramics at normal temperature is 0.9-1 W/m · deg and 1.2-1.5 W/m · deg at 900-1000°C.

In the case of materials 1 and 2 which contain an increased quantity of ferric oxides, the thermal conductivity is 10-15% lower than in the low ferrous materials 3 and 4. This is associated with the more complex structure of the ferrous materials, in which together with pyroxene of augitic composition, there is present a considerable quantity of magnetite (up to 20%). The crystals of magnetite intensively disperse thermal waves and as a result the total thermal conductivity of the cast material is reduced. Moreover the monoclinic pyroxene of augitic composition has a more complex crystalline lattice than pyroxene of diopside composition. Isomorphous fixed displacement of ions of Ca^{2+}, Mg^{2+} and partially of Si^{4+} by ions of Fe^{2+} in the diopside lattice promotes the formation of additional centers of dispersion of thermal elastic waves, which leads to the reduction of the thermal conductivity of the cast materials. The average atomic weight of the particles which form the pyroxene of the diopside composition are somewhat smaller than those of the crystals of pyroxene of the augitic type, which is also conducive to increase of the thermal conductivity of materials 3 and 4.

Hence the structure of cast ceramics and the composition of the main material-forming mineral, monoclinic pyroxene, influences the thermal conductivity of the cast material.

GROWTH OF A VAPOR BUBBLE IN A TUBE

L. M. Gerber, A. M. Kosevich,
S. M. Andon'ev, V. I. Karas',
and V. A. Barannik

UDC 536.423.1

The mechanisms of the growth of a vapor bubble inside a tube are of interest in connection with the effect of the structure of the flow on the condition of its movement round a circulation system, i.e., on the occurrence of pulsations of speed.

A condition of the growth of a vapor bubble is the presence of an internal excess pressure, and consequently, the presence of a certain superheating of the liquid in comparison with the saturation temperature. The growth of the bubble takes place owing to the evaporation of the liquid through its wall.

The growth of the bubble in a large volume, when evaporation goes through displacing boundaries, was investigated previously. In this case the rate of growth of the bubble decreases with time.

The growth of the vapor cavity in a tube with moistened walls, when the bubble covers the whole cross section of the tube, is different in principle. In this case the increase of its volume takes place already not by means of displacement of the whole surface through which the evaporation takes place, but as a result of movement of only the ends of the vapor lock. At the same time evaporation takes place over the whole surface of the bubble, including the side walls which are moistened by liquid. In the case of such a process as distinct from the case of a large volume, as the bubble grows the relationship between the area of the surface of evaporation and the area of the displacing boundary of the bubble increases, which is explained by the continuous increase of the speed of growth of the vapor cavity.

In this work the described process was investigated theoretically and experimentally.

In theoretical analysis the uniformity of the vapor, the incompressibility of the liquid and the equilibrium of the phases on the vapor–liquid boundary were assumed. This enabled the equations of hydrodynamics and thermal equilibrium to be written and solved together approximately for low superheating. An equation which describes the variation of the length of the bubble with time was obtained:

$$\frac{dl}{dt}-\frac{2\lambda}{\rho L R_0 d}\,l\left[T_1-T_k-\frac{\rho_l H T_k}{\rho L}\cdot\frac{d^2 l}{dt^2}\right]=0,$$

the solution of which, describing the initial stage of the process, has the form

$$l(t)=l(0)\exp\left[\frac{4(T_1-T_k)^2\lambda^2}{K^2\nu\rho^2L^2R_0^2}\,t\right],$$

where $l(t)$ is the length of the vapor bubble; R_0 is the radius of the tube; d is the thickness of the layer of liquid near the wall; ρ is the density of the vapor; ρ_l is the density of the liquid; λ is the thermal conductivity; L is the specific heat of vapor formation; ν is the viscosity; T_1 is the temperature of superheated liquid; T_k is the temperature of the phase transformation; K is the characteristic constant ($K \sim 1$).

Subsequently the growth of the vapor bubble is slowed down because of the additional pressure determined by the inertia of the liquid. For sufficiently great lengths of time, the relationship between the rate of growth of the bubble and the time is approximately quadratic.

By using high-speed cinephotography, the process of the growth of the vapor lock in a vertical glass tube was investigated for different cases of superheating.

Gor'kii State University, Khar'kov. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 350-351, August, 1970. Original article submitted December 12, 1969; revision submitted April 10, 1970.

The experiments carried out concerned the exponential nature of the growth of the length of the bubble and the quadratic law relationship between the index of the exponent and the superheating. Comparison of theoretical and experimental results shows that the expressions obtained give a good description of the process of growth of the vapor lock actually taking place in the tube.

The peculiarity of boiling in tubes explains the sharp discharges of liquid observed in practice in the case of bubbling in thin tubes and certain forms of pulsation of the speed of movement of the liquid in the case of circulation through closed circuits.

STATIC AND DYNAMIC CHARACTERISTICS OF A HOT-FILM ANEMOMETER WITH INSULATING COATING

S. A. Drozdov, N. V. Pet'kin,
and V. F. Salokhin

UDC 533.608

In this paper the static and dynamic characteristics are calculated theoretically for a hot film anemometer with insulating coating, when operated both at constant temperature and at constant current. An expression is obtained for the sensitivity ε of the film in static measurements, as a function of the thickness δ of the insulating coating:

$$\varepsilon(\mathrm{Bi})/\varepsilon(0) = (1+\mathrm{Bi})^{-3/2},$$

where $\mathrm{Bi} = (\alpha\delta/\lambda)$, λ is the thermal conductivity of the coating; and α is the heat-transfer coefficient averaged over the sensitive element surface, and proportional to the square root of the speed of the oncoming stream.

The frequency response of the film has been calculated for both modes of operation with small fluctuations of the heat-transfer coefficient α. At high frequency the amplitude characteristic has the form:

a) at constant temperature

$$R(\gamma) = (1+\mathrm{Bi}) \Bigg/ \left[\mathrm{ch}^2\gamma - \sin^2\gamma + \mathrm{Bi}\frac{\mathrm{sh}\,2\gamma + \sin 2\gamma}{2\gamma} + \mathrm{Bi}^2\frac{\mathrm{sh}^2\gamma + \sin^2\gamma}{2\gamma}\right]^{1/2};$$

b) at constant current

$$R(\gamma) = (\mathrm{Bi}\exp\{-\gamma\})/(\mathrm{Bi}^2 + 2\gamma\,\mathrm{Bi} + 2\gamma^2)^{1/2}.$$

Analysis of these expressions shows that constant temperature operation of the film yields a frequency range two orders greater than does constant current operation. For the constant temperature mode the relation between the top limit f of the frequency range and the coating thickness is

$$f \sim \delta^2.$$

In addition, we examined the effect of the inertia of the thermal boundary layer formed on the sensitive element, and found that even for an ideal fluid, it limits the frequency range of measurable flow fluctuations.

The following notation is used: a is the diffusivity of the dielectric coating; ω is the circular frequency of fluctuations; $\gamma = \delta\sqrt{\omega/2a}$ is a dimensionless frequency; and R is the amplitude characteristic.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, p. 352, August, 1970. Original article submitted September 19, 1969; revision submitted April 7, 1970.

INFLUENCE OF THE INITIAL CONDITIONS ON THE TEMPERATURE FIELD OF AN INFINITE PLATE FOR DIFFERENT LAWS OF VARIATION OF THE TEMPERATURE OF THE MEDIUM

S. L. Kleinberg and G. I. Khutskii

UDC 536.2.01

Using the example of an infinite plate, an investigation was conducted into the effect of the initial conditions on the temperature field of an element for various laws of variation of the temperature of the medium, i.e., the linear and exponential laws, and also for thermal shock.

The analysis conducted showed that since for exponential variation of the temperature of the medium and under conditions of thermal shock, as a rule, the maximum temperature drops are formed at the stage of the irregular process, the initial distribution of temperature in the element has considerable influence on their magnitude and the moment of their occurrence. Hence this influence is determined to a considerable extent by the level of intensification of the process.

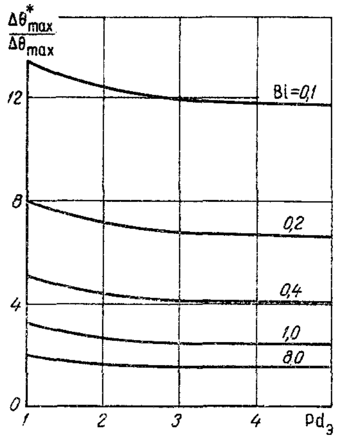

Fig. 1

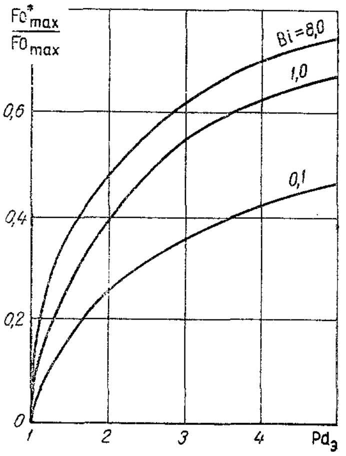

Fig. 2

Fig. 1. Influence of the Predvoditelev number on the relative magnitude of the maximum temperature drops $\Delta\theta^*_{max}/\Delta\theta_{max}$ for various Biot criteria. $\Delta\theta_{max}$ is the maximum temperature drop over the thickness of the plate in the case of uniform initial conditions, $\Delta\theta^*_{max}$ is the same in the case of parabolic initial conditions.

Fig. 2. Influence of the Predvoditelev number on the relative time Fo^*_{max}/Fo_{max} for various Biot numbers. Fo_{max} is the dimensionless time at which the maximum temperature drop sets in over the thickness of the plate in the case of uniform initial conditions, Fo^*_{max} is that for parabolic initial conditions.

Krzhizhanovskii Branch of the Power Institute, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 353-354, August, 1970. Original article submitted February 20, 1969; revision submitted March 15, 1970.

Thus, for example, for an exponential variation of the temperatures with increase of the Biot and Predvoditelev numbers, there is a decrease in the influence of the initial condition on the relative magnitude of the maximum temperature drops $\Delta\theta^*_{\max}/\Delta\theta_{\max}$ (Fig. 1), and an increase in the influence on the relative time $\mathrm{Fo}^*_{\max}/\mathrm{Fo}_{\max}$ of their occurrence (Fig. 2).

For thermal shock, as in the case of exponential variation of the temperature of the medium, the maximum temperature drops depend essentially on the initial temperature differences. Hence with increase of the initial temperature drop, the maximum temperature differences increase in absolute magnitude and they set in at an earlier stage of the process (at low Fo numbers).

As is already known, in the case of a linear law of variation of the temperature of the medium, the maximum thermal drops occur at the stage of the quasisteady-state system. On the strength of this the initial conditions influence only the moment of occurrence of maximum temperature differences, while the magnitude of these differences is determined in an identical manner by the Predvoditelev number.

By using the solution of the equation of thermal conductivity for a linear law of variation of the temperature of the medium and an initial assignment of the temperature as a certain function of the coordinate of the body, the following equation was obtained in this work:

$$\theta(\zeta, \mathrm{Fo}) = \mathrm{Pd}_m\left[\mathrm{Fo} - \frac{1}{2}\left(1 + \frac{2}{\mathrm{Bi}} - \zeta^2\right)\right] + \sum_{n=1}^{\infty}\frac{A_n}{\mu_n^2}\,[(\mathrm{Pd}_m - \mathrm{Pd}_{m-1})$$

$$+ (\mathrm{Pd}_{m-1} - \mathrm{Pd}_{m-2})\exp(-\mu_n^2\mathrm{Fo}_{m,m-1})]\cos\mu_n\zeta\,\exp(-\mu_n^2\mathrm{Fo}),$$

$$\mathrm{Fo}_{m,m-1} = \frac{a(\tau_m - \tau_{m-1})}{R^2}.$$

The derived equation can be recommended for calculation of the temperature field of massive components in the case of arbitrary variation of the temperature of the medium using a piecewise linear approximation of the temperature curve.

NONSTATIONARY TEMPERATURE FIELD IN A SOLID WITH NONLINEAR BOUNDARY CONDITIONS

Yu. V. Vidin

UDC 536.2.01

This paper considers a method for determining a lower limit for the nonstationary symmetric temperature field described by the linear differential equation of heat conduction. The boundary condition describing the supply of heat to the body from the outside is given in the form

$$(\mathrm{grad}\,\theta)_s = f(\theta_s).$$

We assume that the function f is nonlinear with respect to the surface temperature of the body, is monotonically decreasing, and has inverse concavity to the θ-axis. Similar requirements are satisfied, for example, by functions which express radiative or compound heating from a fixed temperature heat source.

A lower limiting temperature field can be established by use of the "sliding" approximation method. The essence of this method consists in replacing, over the time interval (0, Fo*) (where Fo* is the design value of the Fourier number Fo for which it is required to find the temperature distribution inside the body), the actual variation of the function f by an approximate linear variation, namely, $f = a - b\theta$. Here the coefficients a and b depend on the surface temperature $\theta_s^* = \theta(1, \mathrm{Fo}^*)$, which holds at the fixed instant Fo = Fo*. The coefficients a and b can be determined by solving the system of algebraic equations

$$f(\theta_s^*) = a - b\theta_s^*, \tag{1}$$

$$f(\theta_0) = a - b\theta_0. \tag{2}$$

Obviously, the magnitudes of the quantities a and b will vary in passing from one time instant Fo_1^* to another Fo_2^*. Consequently, for each fixed value of Fo* the approximating line $(a-b\theta)$ will have a completely definite angle of inclination to the θ-axis. Therefore it is proposed to speak of this method as the "sliding" approximation method. A general solution of the given linear problem may be found in A. V. Lykov's monograph on heat conduction.†

Since, in accord with the initial premise, the line $(a-b\theta)$ always lies somewhat below the true curve f, the calculated temperature field will always be less than the actual temperature distribution. For the particular case in which the function f degenerates into a linear function, the limiting temperature field and the actual temperature field will coincide.

To find the temperature at a given section at the given time instant Fo = Fo*, it is necessary to have available the numerical values of the coefficients a and b at this particular instant. To determine these, however, it is necessary to know the surface temperature, which is, as yet, unknown. To proceed, then, one first draws the graph of the relationship $\mathrm{Fo} = \varphi(\theta_s)$ by using the available Heisler nomograms, which yield for a given Fo* the corresponding temperature θ_s^*, and then a and b may be calculated. For purely radiative heating the largest departure between the limiting and the actual temperatures does not exceed 8%. The presence of a convective component decreases this difference, the more so the greater the proportion of this component in the total heat flow supplied to the body.

Using the approach described above presents an effective way of calculating the temperature field when an essential nonlinearity is present in the boundary conditions. Moreover the basic idea of representing the function f on the interval (0, Fo*) by the relation $f = a - b\theta$ remains unchanged. However the formulas

---

†A. V. Lykov, Analytical Heat Diffusion Theory, Academic Press, New York (1968).

Polytechnical Institute, Krasnoyarsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 355-356, August, 1970. Original article submitted August 26, 1969; revision submitted March 31, 1970.

for finding a and b may be established by several other concepts. If the selection of a and b is carried out in a special manner, a significant decrease in the deviation between the true and calculated temperature fields can be achieved. Thus, if a and b are determined by using Eq. (1) and the relation

$$\int_{\theta_0}^{\theta_S^*} f(\theta)\,d\theta = \int_{\theta_0}^{\theta_S^*} (a - b\theta)\,d\theta, \tag{3}$$

the maximum relative error in the temperature in the case of radiative heat exchange for a plate is less than 4%. For a cylinder and a sphere the accuracy of the calculation is higher.

AN ANALYTIC ELECTRICAL SIMULATION METHOD FOR SOLVING ONE-DIMENSIONAL NONSTATIONARY HEAT-CONDUCTION PROBLEMS

V. A. Dubrovnyi and E. I. Zabokritskii

UDC 681.142.334:536.21

Thermal devices can be simulated by electrical circuits using either distributed or concentrated parameters. However, the physical simulation requires a real circuit to be set up; the accuracy of the calculations depends on the accuracy of the combination of circuit elements and the measurement of the resulting quantities.

The authors have worked out a special case of the electrical-simulation method: an analytic electrical simulation that does not require the setting up of real models and makes possible the use of the well-developed apparatus of the theory of linear electric circuits for the solution of complicated problems of nonstationary heat conduction, especially for multilayer walls. Although the method of analytic electrical simulation has been used only for solving one-dimensional problems, it can also be used for three-dimensional problems.

The article describes the basis of the method, gives examples of the solution of nonstationary heat-conduction problems by the analysis of T-shaped equivalent circuits with distributed parameters. By using this method it is possible to determine the temperature as a function of time for the outer surfaces of each layer of a plate for any boundary conditions, including asymmetric boundary conditions. If it is required to determine the temperature inside a layer of the plate, two equivalent circuits, connected in series, are set up for this layer.

The analytic electrical simulation method makes it possible to obtain solutions in the form of Laplace transforms. The inversions to the original functions should be carried out in the usual way. In some cases, in fact, inversion is not required – for example, in determining the transfer functions of automatic control systems.

The article also shows, and gives the justification for, the possibility of considerably simplifying the calculations by replacing a plate with an equivalent circuit using concentrated parameters. Such a substitution is possible in the analysis of a thermal process under steady-state conditions. However, in a number of cases with boundary conditions of the second and third kinds, such a substitution is possible from the very outset of the process. For cases in which the Biot criterion does not exceed 0.02, the error in the calculations when this substitution is made will be no more than 1%. These conditions remain valid for a steel plate with a thickness of 90 mm or less and for an aluminum plate with a thickness of 418 mm or less in the examples considered. The calculations for multilayer walls can be carried out by using the analytic simulation method in such a way that some of the layers are replaced by equivalent circuits with distributed parameters, and others by circuits with concentrated parameters. In addition, in order to find the temperature field in a particular layer within a multilayer wall, it is not necessary to solve the entire system of differential equations set up for the entire wall. The method of analytic electrical simulation makes it possible to obtain a mapping of the temperature for the required layer in the simplest possible way.

Technological Institute of Light Industry, Kiev. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 357-358, August, 1970. Original article submitted October 20, 1969; revision submitted March 23, 1970.