ABSTRACTS OF ARTICLES DEPOSITED AT VINITI*

DENSITY OF ISOAMYL ALCOHOL OVER WIDE RANGES IN TEMPERATURE AND PRESSURE

T. A. Apaev, S. I. Lipovetskii,
and A. A. Gylmanov

UDC 536.412

Measurements are reported on the density for isoamyl alcohol of purity 99.4% over the ranges 280-570°K and 1-800 bar; the gravimetric method gives an error of ±0.1%.

The working temperature T was measured with a standard resistance thermometer to 0.01°C, while the pressure P was measured with MP-60 and MP-2500 piston gauges of accuracy class 0.05 with correction for the atmospheric pressure.

A method and equation previously described [1, 2] were used in processing the results:

$$P = A(v) + B(v)\,T, \tag{1}$$

which was given for liquid hydrocarbons, since the P−T sections of the v−P−T surface for liquid isoamyl alcohol are also represented by straight lines throughout the range within ±0.12%. Here A and B are functions of the specific volume v. The physical meanings of these are as follows: $A = -(\partial U/\partial v)_T$, where U is the internal energy, which characterizes the molecular interaction; $B = (\partial P/\partial T)_V$.

Then A and B as functions of v are given analytically as

$$A = -2300.9 + 186.99X - 4.138X^2 - 0.6400X^3 + 0.14304X^4 - 0.01205X^5, \tag{2}$$

where

$$X = 2\cdot 10^4 v - 31, \tag{3}$$

$$B = 0.8071 + 281.5 \exp(-2720\,v). \tag{4}$$

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*All-Union Institute of Scientific and Technical Information.

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ANGULAR EMISSION COEFFICIENTS FOR A PAIR OF COAXIAL CYLINDERS OF FINITE BUT DIFFERENT LENGTHS

Yu. A. Surinov and V. V. Rubtsov

UDC 536.3

All the major working formulas are given for the local and mean emission coefficients for a closed radiating system bounded by a pair of coaxial cylinders. The system consists of six zones: two lateral surfaces, correspondingly, for the internal and external cylinder (zones F_2 and F_5) and the bases of these (zones F_1, F_3, F_4, and F_6).

The essentially new local angular emission coefficients for systems of this type are $\varphi(M_4, F_6)$ and $\varphi(M_5, F_4)$; where $(M_4 \in F_4;\ M_5 \in F_5)$; the working formulas for these coefficients have been derived in finite form by contour integration. Also, a new working formulas has been derived for the mean angular coefficient φ_{54} for the emission from the side surface of the outer cylinder to the base:

for $b_2 \geqslant b_1$ and $H \leqslant \frac{2b_2}{1+r}$

$$\varphi_{54} = \frac{\sqrt{H^2+4}}{4} + \frac{c_2^2 - b_1^2}{4H} - \frac{c_2}{2} + \frac{1}{\pi H}\left\{\frac{H(c_2-b_1)-(c_2^2-b_1^2)}{2}\arccos r + \right.$$
$$+ r\left[c_2 \operatorname{arctg} Q(c_2) - c_1 \operatorname{arctg} Q(c_1) + b_2 \operatorname{arctg} Q(b_2) - b_1 \operatorname{arctg} Q(b_1)\right] +$$
$$\left. + \frac{1}{2}\left[L(c_2)\operatorname{arctg} R(c_2) - L(c_1)\operatorname{arctg} R(c_1) + L(b_1)\operatorname{arctg}\frac{1}{R(b_1)} - L(b_2)\operatorname{arctg}\frac{1}{R(b_2)}\right]\right\} = \varphi; \tag{1}$$

for $b_2 \geqslant$ and $\frac{2b_2}{1+r} \leqslant H \leqslant 2b_2$

$$\varphi_{54} = \varphi + \frac{1}{\pi H}\left\{\left(\frac{c_2H}{2} - \frac{c_2^2}{4} - \frac{H^2}{4} + \frac{1-r^2}{4}\right)\arccos\left[-T(c_2, H)\right] + \right.$$
$$+ \frac{H^2}{4}\arccos\left[-W(c_2, H)\right] + \frac{c_2^2}{2}\operatorname{arctg} K(c_2) - \frac{H\sqrt{H^2+4}}{2}\operatorname{arctg}\frac{1}{V(c_2, H)} -$$
$$\left. - \frac{L(c_2)}{2}\operatorname{arctg}\left[R(c_2)\cdot d_2\right] + \frac{L(b_2)}{2}\operatorname{arctg}\left[\frac{d_2}{R(b_2)}\right] - \frac{1-r^2}{2}\operatorname{arctg} K(c_2)\right\}; \tag{2}$$

for $b_1 \geqslant b_2$ and $H \leqslant \frac{2b_1}{1+r}$

$$\varphi_{54} = \frac{\sqrt{H^2+4}-H}{4}. \tag{3}$$

Here

$$K(x) = \sqrt{\frac{1-r}{1+r}} \cdot \sqrt{\frac{H(1-r)-2x}{2x-H(1+r)}};\ L(x) = \sqrt{(x^2+r^2+1)^2-4r^2};$$
$$Q(x) = \frac{x}{\sqrt{1-r^2}};\ R(x) = \sqrt{\frac{x^2+(1+r)^2}{x^2+(1-r)^2}} \cdot \sqrt{\frac{1-r}{1+r}};$$
$$T(x, t) = \frac{2x-t(1-r^2)}{2xr};\ V(x, t) = \sqrt{\frac{(t^2+4)(r^2-1)}{4x^2-4xt-(r^2-1)t^2}};$$
$$W(x, t) = 1 + \frac{(1-r^2)t^2}{2x(x-t)};\ d_2 = \sqrt{\frac{H(1-r)-2c_2}{2c_2-H(1+r)}};\ c_i = H - b_i;\ (i=1, 2),$$

where $H = H'/R'$; $r = r'/R'$; $b_i = b_i'/R'$; H' and R' are the length and radius of the outer cylinder; and b_i' is the distance between the bases of the cylinders. The working formulas and expressions have been used in numerical calculations, the results being presented as graphs.

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CALCULATED COMPARISON OF METHODS FOR TAKING ACCOUNT OF THE SELECTIVITY OF THE OPTICAL PROPERTIES OF A MEDIUM IN PROBLEMS INVOLVING RADIATIVE HEAT EXCHANGE

M. A. Denisov

UDC 536.3

In this study we compare the results of calculations made by three methods representing fundamentally different approaches to the description of the selective properties of gas radiation. The calculations were carried out for heat exchange through radiation in a medium filled with carbon dioxde.

The combined model used in this study describes the resulting heat exchange of a nonisothermal layer of gas with gray walls, using the method of multiple reflections. In accordance with this, the resulting heat flux hitting wall 1, which bounds the plane layer of gas, is calculated as the sum of the heat fluxes hitting the wall from the radiation of the gas and from the radiation of walls 1 and 2 themselves. The calculation of the radiation of the nonisothermal layer of gas in the direction of the walls is carried out by a method based on Nevskii's approximation [1, 2] and using data on the total radiation of the gas. The absorptive capacities of the gas with respect to the black radiation from the walls are determined by Hottel's formula for the average temperature of the layer. The absorptive capacities of the gas with respect to the radiation of the gas are determined in accordance with [2].

The results of the calculation of the resulting heat fluxes of the radiation on the basis of the combined model were compared with the more exact calculations of Popov [3]. In this, the statistical model of absorption bands developed by Goody for an isothermal medium was generalized to the case of inhomogeneous and nonisothermal media. In the calculations the internal structure of the absorption bands of the gas was taken into account.

We compared the results of the calculation with the calculations made on the basis of the selective-gray model with a fixed width for the gas absorption bands [4] and with the results of the calculation carried out on the basis of the gray-gas model. In the latter, the effective dimension of the layer was taken to be equal to 1.8 times its height.

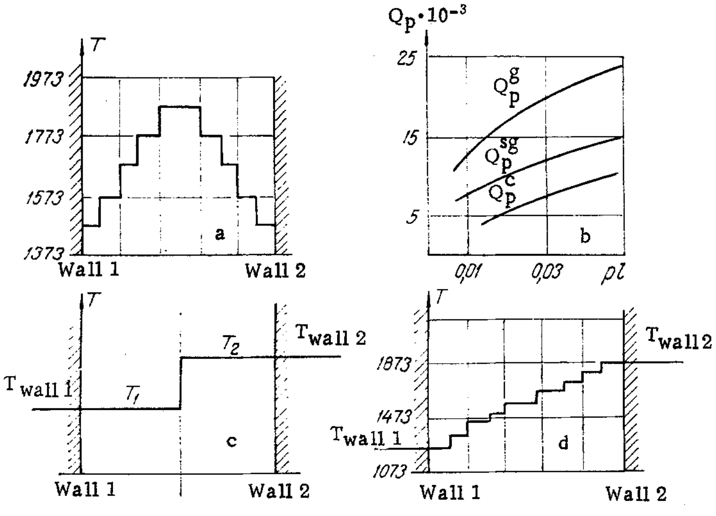

Fig. 1. The investigated temperature distributions in the layer and the heat fluxes of radiation to the walls. T, °K; pl, m · atm; Q_p, W/m^2.

The variation of the resulting heat fluxes to the walls determined on the basis of the gray model Q_p^g, the selective-gray model Q_p^{sg}, and the combined model Q_p^c as a function of the product of the partial pressure of the gas and the layer dimension pl for the temperature distribution (Fig. 1a) is shown in Fig. 1b. In this case the calculation on the basis of the gray model yielded results which were about twice as high. The calculation by the selective-gray model also yielded increased values for the resulting fluxes to the walls, since the variation of the gas absorption bandwidth as a function of temperature was not taken into account.

The comparison showed that the results of the calculations of the gas radiation (Fig. 1c) in the direction of the arrow on the basis of the combined and statistical models are about the same. Substantial differences were found only for a very low temperature, $T_1 \sim 500°K$.

In this study we compare the results of the calculation of the resulting radiation to the walls according to the gray, statistical, and combined models as functions of the degree of blackness of the walls for the temperature distribution (Fig. 1c). We compared the calculations according to the combined, selective-gray, and gray models for the temperature distribution shown in Fig. 1d. In both cases the compared models yielded approximately the same calculation results.

We conclude that for an asymmetric temperature distribution in the gas layer, if one wall is hot and the other is colder (for example, in heating furances, when the radiation from glowing hot masonry hits the cold metal), practical calculations for heat exchange through radiation can be carried out by using the gray-gas approximation.

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Original article submitted January 14, 1976.

CALCULATIONS ON THE COOLING OF A HEAT BRIDGE BY HELIUM VAPOR

B. V. Eliseev, Yu. P. Mordvinov,
and L. P. Pasechnik

UDC 621.1.016.4

The heat influx to the cold zone through heat bridges is often minimized by cooling the bridges with gaseous helium.

A solution is presented for the heat transfer in a planar bridge cooled by a longitudinal flow of helium under laminar and turbulent conditions, with allowance for the variations in properties of the gas and material along the bridge.

The initial equations in dimensionless form are as follows in the thin-fin approximation:

$$\frac{d}{dx}\left(\lambda \frac{dT}{dx}\right) - \frac{\alpha \Pi}{S}(T - T_g) = 0, \tag{1}$$

$$\frac{dT}{dx} - \frac{\alpha \Pi}{GC_p}(T - T_g) = 0. \tag{2}$$

The boundary conditions are $x = 0$, $T = T_0$, $T = T_{g0}$; $x = 1$, $T = T_1$; computer calculation for a stainless steel bridge was performed by iteration with linear interpolation.

The influxes at the ends have been derived, together with the temperature distributions in the bridge and in the helium. Two different states of heat transfer occur in different ranges in Reynolds number. Figure 1

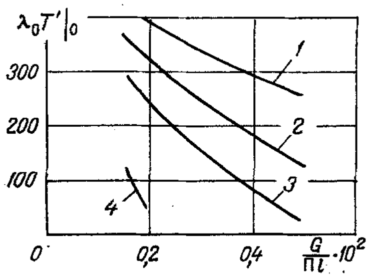

Fig. 1. Heat influx to the cold end of a bridge as a function of $G/\Pi l$ for values of $S/\Pi l^2 (m^{-1})$ of: 1) 50; 2) 30; 3) 20; 4) 5. $T_0 = 10°K$, $T_{g0} = 8°K$, and $T_1 = 100°K$.

shows the heat fluxes at the cold end in relation to $G/\Pi l$ for $S/\Pi l^2$ (m^{-1}) of 50, 30, 20, and 5 (turbulent state). There are clearly limiting flow rates at which the heat flux becomes essentially zero. The temperature distributions also indicate clearly the transition from turbulent to laminar heat transfer.

NOTATION

T, T_g	are the temperatures of bridge and gas °K;
$\lambda(T)$	is the thermal conductivity of material, W/m·deg;
C_p	is the specific heat of helium, J/kg·deg;
G	is the helium flow rate, kg/sec;
S	is the cross-sectional area, m^2;
Π	is the perimeter of cross section, m;
l	is the bridge length, m;
$\alpha(T_g)$	is the convective heat-transfer coefficient, $W/m^2 \cdot deg$.

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Original article submitted February 18, 1976.

REGULARIZATION OF THERMAL KINETICS FOR A LIQUID FLOWING IN A CHANNEL

N. M. Tsirel'man

UDC 536.21

An analysis is presented of the temperature distributions arising during stabilized laminar flow in a liquid with constant thermophysical parameters in a channel for boundary conditions of the first, second, and third kinds. It is found that the rate $\bar{v}_\theta$ at which the isothermal surfaces approach the axis (plane) of the channel in the stabilized heat-transfer region is independent of the position of the cross section and is determined solely by the nature of the boundary conditions, the form of the channel, and the distance of the isothermal surface from the wall. The local rate of approach $\bar{v}_\theta$ is independent of the choice of the cross section, which is an indication that heat transfer has become stabilized, which can be used in addition to the global feature (absence of variation in the heat-transfer rate along the channel).

Figure 1 shows the zones of regular and heat transfer correspond to the equidistant parts of the curves representing the various isotherms θ = idem (the appropriate region is defined by the dashed curve).

In the central part, where the flow is laminar; $\bar{v}_\theta$ is independent of the thermal conditions at the outer surface of the channel and is defined by

$$\bar{v}_\theta = \left[\frac{\partial (1-\xi)}{\partial \tau}\right]_\theta = \frac{m}{\xi}.$$

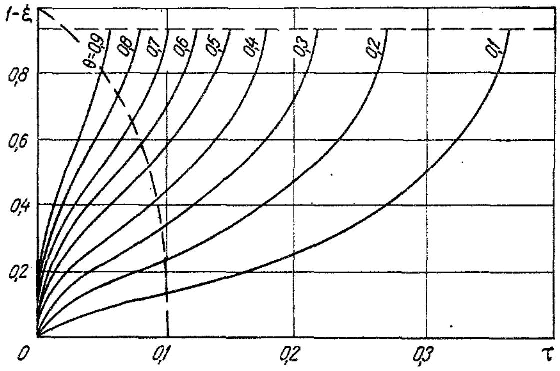

Fig. 1. Positions of the isotherms in a circular pipe for boundary conditions of the first kind.

The rate of approach of the isotherms to the core for a tubulent flow is described by the following formula for the stabilized range:

$$\bar{v}_\theta = \left(1 + \frac{a_T}{a}\right)\frac{m}{\xi}.$$

NOTATION

$\xi = y/l_0$ and y, l_0	are the dimensionless and dimensional coordinates of a point in the pipe and characteristic pipe dimension;
$\tau = at/l_0^2$, $t = x/w$	are the dimensionless and dimensional times;
w	is the speed at the axis for laminar flow and mean speed for a turbulent flow;
a, a_T	are the molecular and turbulent thermal diffusivities;

x is the distance from the inlet cross section;
$m = 1, 2$ are the planar or circular pipes, respectively.

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Original article submitted January 5, 1976.

FLOW OF AN AXIALLY SYMMETRICAL LAMINAR JET INTO AN IMMISCIBLE LIQUID

V. I. Eliseev and L. A. Fleer

UDC 536.532.2

Results are presented on jet flows for immiscible liquids; here there is always an interface between one liquid and the other. A simple formulation is used, with laminar flow and the interface a smooth surface at which the velocities are equal, as are the tangential and normal stresses, the temperatures, and the heat fluxes. The conditions for conservation of momentum

$$I = \int_0^{r_*} \rho_1 u_1^2 r dr + \int_{r_*}^{\infty} \rho_2 u_2^2 r dr = \text{const}$$

and for the integral expression

$$H = \int_0^{r_*} c_1 \rho_1 r u_1 \theta_1 dr + \int_{r_*}^{\infty} c_2 \rho_2 r u_2 \theta_2 dr = \text{const},$$

apply here, as for miscible jets, where the subscript 1 relates to the liquid jet and 2 to the adjoint mass, with r_* the interface between the two liquids. In addition, there is the mass-conservation condition for the liquid jet:

$$G = \int_0^{r_*} \rho_1 r u_1 dr = \text{const}.$$

These integral conditions are derived on integrating the equations for the boundary layer subject to homogeneous boundary conditions at the axis of the jet and at infinity, together with the above conditions at the interface.

The flow of a planar laminar jet under such conditions has previously been considered by an integral method [1]; here an asymptotic solution is presented that allows one to calculate the flow distribution far from the source. Analytical expressions are derived via two approximations for the velocities and temperatures at the axis. It is shown that the solutions go over to standard formulas for a jet of miscible liquid if $G \to 0$, and the corresponding parameters with subscripts 1 and 2 are equal.

NOTATION

r is the transverse coordinate;
ρ_i is the density;
u_i is the longitudinal velocity;
$\theta_i = T_i - T_\infty$;
T_i is the temperature;
T_∞ is the temperature at infinity;
c_i is the specific heat.

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Original article submitted August 26, 1975.

FLOW PARAMETERS ON INJECTING A LIQUID INTO A SUPERSONIC FLOW

M. S. Volynskii and V. A. Yampol'skii

UDC 629.7.037:(621.43-44)

The parameters of a two-phase flow have been determined by extending a previous model [1], with the injected jet having two characteristic parts: an initial section in which hydromechanical processes and phase transitions can be neglected and a second part where phase transitions occur, with the main and injected flows mixing. Only the initial part is considered here.

The incident flow past the shock wave is divided into two parts, with one penetrating into the jet (zone 1) and the other flowing around it (zone 2). Mean parameters are introduced for the cross section, which characterize the equivalent one-dimensional flows in the jet and in the adjacent stream.

A system of equations is formulated for the conservation of matter and energy in zone 1 and also for the conservation of the total flow rate and momentum in zones 1 and 2, together with the equation for energy conservation in zone 2 and a relationship for the entropy increase in the gas on passage through the oblique shock wave in zone 2.

The positions of the jet and shock wave are derived from an empirical relation [1]. The resulting system of nonlinear algebriac equations is solved by parametric extension [2]. This involves passing from a system of algebraic equations to ordinary differential equations in terms of a certain parameter, with the latter solved numerically. Results are presented on the flow parameters and jet values in relation to the relative velocity U' for a droplet and the gas in the monitor section. If $U' \simeq 1/2\, U_{max}$ is used to estimate U', where U_{max} is the maximum speed allowed by the dispersal criterion $\rho' U^2_{max}\, a/\sigma = D (D \simeq 10.7)$, then the gas flow is subsonic emerging from the initial part. Here ρ', a, and σ are the gas density, droplet diameter, and surface tension.

Results are presented for the static pressure and mean liquid concentration along the axis of the jet. The pressure falls away from the point of injection, which is due to fall in the intensity of the shock wave, the result being described satisfactorily by $p'/p_\infty = 1 + A/\bar{x}^\alpha$, where p', p_∞ and are the static pressure in the jet and in the incident flow, with $\bar{x}$ the distance from the point of injection. The calculations are compared with measurements on pressures at the axis of the jet [3] on injecting ethanol into a supersonic air flow having $M = 3.95$, $p_0 = 20.5$ atm, and $T_0 = 283°K$. The discrepancies do not exceed about 20%.

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Original article submitted May 27, 1975.

CONVECTIVE STABILITY IN A HORIZONTAL LAYER OF AN ELASTOVISCOUS LIQUID WITH A SHORT MEMORY TIME

F. A. Garifullin and A. B. Gabitova

UDC 532.135-536.25

Various features arise in the convection in horizontal layers of viscoelastic liquids.

A difference from a Newtonian liquid, where only stationary instability is possible, is that the system of equations for an elastoviscous liquid is not self-conjugate, so there can be complex eigenvalues (oscillatory instabilities can accompany monotonic ones).

The oscillatory branch in the instability spectrum is here related to the relaxation mechanism. The relevant quantity is the ratio between the relaxation times for the temperature and the viscous-stress tensor.

A planar horizontal layer heated from below is considered; the rheology is described by an Oldroyd–Walters relation of contravariant type [1].

A linear formulation is employed, and the dispersion equations for the perturbation amplitudes for the velocity and temperature are examined for several particular rheological models and compared with known results.

Ideally thermally conducting boundaries are envisaged (two rigid ones).

The treatment is by means of Chandrasekhar's variational method [2].

The fundamental mode in the instability is considered for the even and odd solutions, which serves to define the critical Rayleigh number in terms of the elasticity parameters and the Prandtl number.

If the memory time is short, the stability threshold is determined by the Rayleigh number corresponding to the stationary instability, which confirms the conclusion [3] that the maximum Newtonian viscosity can be determined by means of the critical Rayleigh number for the monotonic instability.

Values are derived for the critical parameters for oscillatory instability for a Maxwellian liquid. The relaxation time destabilizes the layer considerably on heating from below.

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Original article submitted April 6, 1974.

DEPLETION OF A GAS CAVITY IN THE PRESENCE OF HEAT TRANSFER

N. P. Belik and L. G. Chirva

UDC 533.17:536.242

An engineering method is presented for calculating the depletion of a gas cavity in which there is influx of heat from the wall. The heat transfer is assumed to be by means of free convection. Then the heat transferred to the gas is a nonlinear function of the pressure and to temperature difference. This expression may be linearized over two ranges: in the range of falling gas temperatures ($p_* < p < p_0$, $T_* < T < T_0$) and that of rising temperatures ($0 < p < p_*$, $T_* < T < T_0$), which provides working formulas for the basic thermodynamic parameters (p_* and T_* are the gas pressure and temperature at the point of inflection on the temperature curve). These can be determined approximately from formulas previously published for such calculations on gas vessels [see Inzh.-Fiz. Zh., No. 9 (1964)]. Calculations from these formulas agree satisfactorily with experiment.

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Original article submitted March 29, 1976.

A GENERALIZED GIBBS EQUATION FOR NONAUTONOMIC INTERPHASE REGIONS

É. V. Veitsman

UDC 536.755+532.6+541.11

A generalized (entropy) Gibbs equation is derived for the interphase region when the distribution of the external forces is nonstationary and the field rotor is zero. The equation takes the form

$$T d\overset{+}{s} = d\overset{+}{u} - \tau_{ij} d\varepsilon_{ij}/\rho - \sum_{\kappa} \overset{+}{\mu}_{\kappa} d\overset{+}{N}_{\kappa} - \sum_{\kappa} \overset{+}{N}_{\kappa} d_t \overset{+}{e}{}'_{\kappa}, \quad \overset{+}{e}{}'_{\kappa} = \tau'_{ij}\delta_{ij}/\rho_{\kappa}, \quad \tau'_{ij} \equiv (\tau_{\kappa})_{ij}. \tag{1}$$

This equation (1) has been used in the linear thermodynamics of irreversible and nonstationary processes as applicable to surface layers. Prigogine's method [1] has been used, i.e., the entropy production $\sigma[S]$ is determined along with the dissipative function Ψ and the generalized fluxes and forces. The derivation of $\sigma[S]$ is based on (1) and the local energy balance. The local potential-energy balance is supplemented by a term Z on the right that incorporates the nonstationary external forces:

$$Z = -\sum_{\kappa} \rho_{\kappa} F^{\kappa}_{\beta} \omega^{\kappa}_{\beta} = -\sum_{\kappa} \rho_{\kappa} \partial \overset{+}{e}{}'_{\kappa} / \partial t.$$

An essentially new expression for the generalized mass-transfer force is obtained:

$$X^{\kappa}_{\beta} = F^{\kappa}_{\beta} - \frac{\partial F^{\kappa}_{\beta} r^{\kappa}_{\beta}}{\Delta^{\kappa}_{\beta} \partial t} - \left(\frac{\partial \overset{+}{\mu}_{\kappa}}{\partial x_{\beta}} \right)_T$$

The theory of surface forces given in [2, 3] has been used in formulating the nonequilibrium and nonstationary thermodynamics of surface films.

The following phenomenological laws are derived:

$$v_{\Omega} = \sum_{\Omega'=1}^{R} a_{\Omega\Omega'} A_{\Omega'} + a_{\Omega q} (X_q)_{\beta} + \sum_{\kappa=2}^{N} a_{\Omega\kappa} \left(X^*_{\kappa}\right)_{\beta} \delta_{\beta} + a_{\Omega p} X_{i\beta} \delta_{i\beta},$$

$$\left(I^*_{\kappa}\right)_{\beta} = \sum_{\Omega=1}^{R} a_{\kappa\Omega} A_{\Omega} \delta_{\beta} + a_{\kappa q} (X_q)_{\beta} + \sum_{\kappa'=2}^{N} a_{\kappa\kappa'} \left(X^*_{\kappa'}\right)_{\beta} + a_{\kappa p} X_{i\beta} \delta_i,$$

$$(I_q)_{\beta} = \sum_{\Omega=1}^{R} a_{q\Omega} A_{\Omega} \delta_{\beta} + a_{qq} (X_q)_{\beta} + \sum_{\kappa=2}^{N} a_{q\kappa} \left(X^*_{\kappa}\right)_{\beta} + a_{qp} X_{i\beta} \delta_i,$$

$$P_{i\beta} = P_{\beta i} = \sum_{\Omega=1}^{R} a_{p\Omega} A_\Omega \, \delta_{i\beta} + a_{pq} (X_q)_i \, \delta_\beta +$$

$$+ \sum_{\kappa=2}^{N} a_{p\kappa} \left(X_\kappa^*\right)_i \delta_\beta - \eta \left(\frac{\partial w_i}{\partial x_\beta} + \frac{\partial w_\beta}{\partial x_i} \right) + \left(\frac{2}{3} \eta - \varsigma \right) \delta_{i\beta} \frac{\partial w_j}{\partial x_j} .$$

The first attempt to formulate phenomenological laws for anisotropic regions is to be found in [4], but various errors were made there, which have now been eliminated.

NOTATION

T	is the absolute temperature;
s, u^+	are the specific entropy and internal energy (J/kg);
τ_{ij}	is the stress tensor;
ε_{ij}	is the strain tensor;
ρ, ρ_k	are the density and partial density of material of type "k";
$\overset{+}{\mu}_k$	is the specific chemical potential of material type "k";
$\overset{+}{N}_k = \rho_k/\rho$; τ'_{ij}	is the component of τ_{ij} due to the force F_β^k;
F_β^k	is the external specific force on particles of type "k";
w_β^k	is the speed of particles of type "k";
$\Delta_\beta^k = w_\beta^k - w_\beta$; w_i, w_j, w_β	are the velocity vectors for the center of mass;
r_β^k	is the radius vector for the center of mass for particles of type "k";
δ_{ij}, $\delta_{i\beta}$	are the Kronecker symbols;
x_β	is the coordinate ($\beta = 1, 2, 3$);
$P_{i\beta}$	is the generalized flux in viscous flow;
$X_{i\beta}$	is the generalized force in viscous flow;
I_q and X_q	are the generalized flux and force in heat transfer;
$(I_k^*)_\beta$, X_β^k, $(X_k^*)_\beta$	are the generalized flux and force in mass transfer;
A_Ω	is the de Donde affinity;
$v \equiv d\xi_\Omega/dt$	is the reaction rate;
ξ_Ω	is the extent of reaction Ω:
$a_{\Omega\Omega'} = a_{\Omega'\Omega}$; $a_{kk'} = a_{k'k}$; $a_{\Omega k} = a_{k\Omega}$; $a_{kq} = a_{qk}$; $a_{pq} = -a_{qp}$; $a_{\Omega p} = -a_{p\Omega}$; $a_{kp} = -a_{pk}$	are the phenomenological Onsager and Onsager–Casimir coefficients;
η	is the viscosity;
ξ	is the bulk viscosity coefficient;
δ_i, δ_β	are the unit dimensionless vectors having matrix (III).

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AN ANALYTICAL STUDY OF A VARIABLE-OUTPUT TRAVELING ELECTRIC OVEN

V. V. Tregubov and V. I. Kusov

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This type of continuous-action oven is used in processing strips, and the temperature distribution in the steady state varies along the length of the oven, while the heater temperatures are kept constant within the controlled zone. Output fluctuations occur on account of speed changes and also changes in width and thickness in the strip, which lead to altered temperature distributions in the oven zones.

When a new steady state has been reached, the individual temperatures stabilize and the approach to the new stationary state can be defined by the following equations:

$$dQ = \frac{G_{\text{M}}C_{\text{M}}}{F}\left[W_{\text{M}}\frac{\partial t_{\text{M}}(x,\ \tau)}{\partial x} + \frac{\partial t_{\text{M}}(x,\ \tau)}{\partial \tau}\right] dx d\tau, \tag{1}$$

$$dQ = \alpha\left[t_{\text{H}}(x,\ \tau) - t_{\text{M}}(x,\ \tau)\right] dx d\tau, \tag{2}$$

$$\left\{\frac{M - q_{\text{loss}} - q_{\text{g}}}{F} - \alpha\left[t_{\text{H}}(x,\ \tau) - t_{\text{M}}(x,\ \tau)\right]\right\} dx d\tau = \frac{P_{\text{H}}C_{\text{H}}\partial t_{\text{H}}(x,\ \tau)}{F\partial\tau}\, dx d\tau, \tag{3}$$

where G_M and P_H are strip mass and heater mass, respectively, in kg; F is the area of the heated strip in m^2; W_M is the speed of the strip in m/h; C_M and C_H are the specific heats of the metal and heaters in kcal/kg • deg; $t_M(x, \tau)$ are the temperatures of strip and heaters in °C; M is the input power to the heaters in kcal/h; q_{loss} is the heat loss from the oven in kcal/h; q_g is the heat loss to the protective gas in kcal/h; and α is the heat-transfer factor in kcal/m^2 • deg.

System (1)-(3) has been solved analytically and by Minsk-22 computer. The results allow one to evaluate the transient state in such ovens. For instance, if the actual output deviates by 20-30% from the nominal one, the transient response lasts no more than 2-3 min.

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MASS TRANSFER IN FREEZING SANDS

N. S. Ivanov, N. N. Kozhevnikov,
and A. S. Kurilko

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The investigations are carried out with sands from quarries in Western Siberia and Central Yakutia and consist in determining the intensity and direction of mass transfer, studying the behavior of the moisture content on the freezing front from the direction of the melted zone, and estimating the value of the diffusion coefficient for positive temperatures close to the freezing temperature of the moisture in the sands. The investigations involve the selection of samples in specified regions of frozen specimens and determing the moisture content in these samples by a standard weight method [3]. The initial moisture content varies from values which are safe from the standpoint of freezing to values representing complete saturation with moisture; the temperature of the surrounding medium ranges from −10 to −40°C. To determine the diffusion coefficient, we use one of the modifications of the method of isothermal nonstationary mass flow, consisting in simplification of its calculation part [1, 4]. The investigations are carried out at initial moisture content values of 5, 7, 10, and 15% and temperatures of 2, 5, 10, and 15°C.

The differences between the compared average values of moisture content are considered significant starting from values of 0.75%. In determining the diffusion coefficient the confidence interval does not exceed 10^{-5} m²/h [3, 5]. An analysis of the experimental material led to the following conclusions.

In different ranges of variation of the initial moisture content values, the mass transfer in freezing sands takes place in different ways: From safe values to some critical values, it can be disregarded within the limits of experimental error; from critical values to some transitional values, there is a migration of the moisture in the melted zone toward the freezing front; and from transitional values to saturation moisture content values, the moisture is extended from the freezing front into the melted zone. The critical and saturation moisture content values, respectively, are 9-12%and 22-23% in Kichiga and Bas'yanovskii sands and 6-8% and 24% in Yakutsk sand. The limiting moisture content values for all the sands investigated lie in the 18-20% range.

The moisture content on the front of phase transition from the direction of the melted zone is not a physical parameter but is formed during the freezing process. An empirical formula is proposed for determining this value. The diffusion coefficient values lie between $2 \cdot 10^{-5}$ and $23 \cdot 10^{-5}$ m²/h [2].

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COEFFICIENTS OF MASS-TRANSFER EFFICIENCY IN MULTICOMPONENT MIXTURES

V. V. Raiko and I. A. Aleksandrov

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The process of mass exchange in the rectification of mixtures is determined by the kinetics of mass transport and the hydrodynamics of interaction between vapor and liquid flows. The Murphree coefficients of mass-transfer efficiency (MEC) are used as the kinetic characteristics which account for the inequality of the degree of contact between phases.

Practical calculations of MEC are based on determining the practical diffusion coefficients (PDC), which take into account the nonideality of the mixture to be separated. The calculation of PDC in a multicomponent mixture is simplified considerably by interpreting the kinetic coefficients of the phenomenological equations of mass transfer as "friction coefficients," which makes it possible to represent the algorithm for calculating PDC in a unique form for both the gaseous and the liquid phase. The relationship between PDC and the "friction coefficients" is established by solving simultaneously the system of phenomenological diffusion equations, Fick's equations of molecular transport of matter, and the Gibbs–Duhem equation.

The concentration dependence of the friction coefficient in the liquid phase is determined by means of a theoretical equation derived on the basis of the modified theory of absolute reaction rates and expressed in terms of an exponential function of the composition.

In this case, a relationship derived on the basis of the Chapman–Enskog theory is used for the gaseous phase.

Thus, a unique mathematical description of multicomponent diffusion in both phases with an allowance for the nonideality of multicomponent mixtures and the motive forces with respect to all components has been proposed.

The efficiency of mass transport is analyzed on a model characterized by the additivity of resistances to mass transport in the phases for cross currents under conditions of ideal displacement for the vapor phase and incomplete mixing with an allowance for transverse nonuniformity in the liquid phase. A section model with a liquid bypass is used as the model of the hydrodynamic structure of liquid flow.

On the basis of the linearized theory of mass transfer, the matrices of the coefficients of integral mass-transfer efficiency are determined successively as functions of PDC matrices in the gaseous and the liquid phases, matrices of unit transport numbers, and matrices of local mass-transfer efficiency. Thus, the algorithm for calculating the matrices of integral mass-transfer efficiency is reduced to the calculation of functions of matrices by means of Sylvester's formula.

On the basis of the proposed algorithm, we composed a computer program and calculated the concentration of vapor leaving the contact devices of the apparatus in the rectification of a mixture of hydrocarbons. The Chueh–Prausnitz and Chao–Seider correlations are used for determining the molar volumes, the volatility factors, and the activity.

Comparison between the calculation results and experimental data showed good agreement for component concentrations along the height of the apparatus.

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A METHOD FOR SPECIFYING COMPLEX BOUNDARY CONDITIONS IN CALCULATING THE SOLIDIFICATION OF AN INGOT BY MEANS OF AN ELECTRONIC COMPUTER

L. I. Urbanovich, V. A. Emel'yanov,
A. P. Girya, and E. P. Karamysheva

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For the mathematical description of the temperature field in a continuous ingot we used a two-dimensional equation of nonstationary heat conduction, taking account of the generation of the heat of crystallization in the liquidus–solidus temperature interval [1]. Complex boundary conditions of the third kind were specified.

Using the method of removal of heat in the secondary-cooling zone, we distinguished several types of surface segments: 1) with air cooling (radiative and convective); 2) shielded by the bars (contact heat exchange); 3) subjected to the direct effect of the sprayer jets; 4) sprinkled by water flowing down beyond the limits of action of the sprayer jets.

The distribution of the heat-transfer coefficient α at the point of impact of the water jets was specified by a function of the form

$$\alpha = \frac{\alpha_\infty}{\exp\left[\left(1 - \frac{x^2}{a^2} - \frac{y^2}{b^2}\right) \ln \frac{\alpha_\infty}{\alpha_0}\right]}, \qquad (1)$$

where x and y are coordinates along the horizontal and vertical axes of an ellipse (the ellipse is the shape of the zone of action of the spray jet); a and b are the semimajor and semiminor axes of the ellipse.

According to formula (1), the maximum value of the heat-transfer coefficient, $\alpha = \alpha_0$, is obtained at the center (α_0 is of the order of 10^3-10^4 W/(m^2·K) [2]) and the minimum, $\alpha = \alpha_\infty$, is obtained at the boundary of the region because a bubble regime is established at the center of the zone and a transition regime closer to its boundaries. Beyond the limits of action of the spray or jets, in the region of the descending liquid, the value of α is not large: α_∞ = 175-230 W/(m^2·°K), and this is due to the presence of a buffer steam or steam–air film [2].

In order to formulate an effective program for specifying the local coefficients of heat transfer, we subdivided the complicated picture of the cooled surface into a number of simpler pictures; and through successive formalized analysis of the latter, we found the value of the heat-transfer coefficient at each point of the surface.

The proposed method was used in calculations of the solification and cooling of a continuous steel ingot on the M-222 electronic computer. An analysis of some calculation results is given.

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PROCEDURE FOR CALCULATING THE TEMPERATURE FIELD OF A CONTINUOUS INGOT IN A CRYSTALLIZER

L. I. Urbanovich, V. A. Emel'yanov,
A. P. Girya, and E. P. Karamysheva

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We solved the two-dimensional problem of the solidification of a continuous steel ingot with a rectangular cross section in a crystallizer. Unlike previous investigations, in our study the coefficient of heat transfer along the height of the ingot was specified in the form of a continuous, monotonically decreasing function. This approach agrees with the known experimental fact that the heat removal is more intensive in the upper part of the crystallizer and with the latest ideas concerning the presence of a pulsating contact between the envelope of the ingot and the walls of the crystallizer. The heat-transfer coefficient α was given by the formula

$$\alpha_{i,j}=\frac{\alpha_0}{(h+1)^{n_{i,j}}}, \tag{1}$$

where

$$n_{i,j}=\frac{\ln\frac{\alpha_0}{\alpha^k_{i,j}}}{\ln(h_c+1)}; \tag{2}$$

$$\alpha^k_{i,0}=ax^{0.5}+b;\quad \alpha^k_{0,j}=a_1y^{0.5}+b_1. \tag{3}$$

For the wide face $j = 0$ and $i = 0, 1, 2, \ldots$; for the narrow face $i = 0$ and $j = 0, 1, 2, \ldots$

The solution was carried out numerically on the M-222 electronic computer. We calculated the temperature distribution along the cross section, the densities of heat fluxes along the perimeter, and the thicknesses of the skin along the wide and narrow faces. The mathematical model was made more precise by comparing the calculated values of the amount of heat removed from the ingot with the experimental value of heat removal for a given crystallizer. The calculations were terminated when the indicated values agreed with the required accuracy. We carried out calculations for an ingot with a cross section of 0.24 × 1.71 m^2 for withdrawal velocities of $0.66\cdot10^{-2}$ and $0.98\cdot10^{-2}$ m/sec. The calculated results were found to agree well with the experimental data.

NOTATION

h	is the height of ingot measured from the meniscus;
h_c	is the working height of the crystallizer;
α_0	is the heat-transfer coefficient for $h = 0$;
$\alpha^k_{i,j}$	is the heat-transfer coefficient for $h = h_c$;
a, b, a_1, b_1	are the constants.

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