quacy within the limits 15%. Figure 4 shows the analogous curves for a channel with a screw insert.

Previously, Nazmeev and Mumladze [7] solved this problem by using the iteration method of variable directions.

NOTATION

R, φ, z, polar coordinates; R', φ', z', new independent variables with helical symmetry; S, pitch; P, pressure; V_r, V_φ, V_z, radial, circular, and axial components of the flow velocity; μ, effective (structural) viscosity; Ω, the region; Γ, boundary of the region; F, functional subject to minimization; I_2, second invariant of the deformation velocity tensor; A_n, coefficients of the basis function; i, j, exponents of the power; Φ, fluidity of the non-Newtonian liquid; φ_0, φ_∞, fluidities for $\tau \to 0$ and $\tau \to \infty$; τ, intensity of the shear stress; θ, τ_1, measure and limit of the structural stability of the liquid; k, number of the iteration; L, an operator; U and h, arbitrary functions which satisfy the boundary conditions U, $h|_\Gamma = 0$; L_u', derivative of the operator L; $\bar{e}_1$, $\bar{e}_2$, unit vectors of the cylindrical coordinate system; β, exponent of the power in the rheological model; $(L_u'h, h)$, $(L(tU), U)$, $(\partial P/\partial z, U)$, scalar products in the space L_2; $\|h\|^2$, square of the norm of the element h in space L_2; R, radius of the tube; R_1 and R_2, radius of the inner surface of the outer tube and the radius of the outer surface of the inner tube; $\bar{V}$, mean-flow-rate velocity of the flow; f_n (n = 1,...,m), a complete and linearly independent system of elements; B, a related operator; J_k, Bessel functions; and ν_{kp}, root of the Bessel function.

LITERATURE CITED

1. Yu. G. Nazmeev, "Intensification of the convective heat exchange by twisted strips in the flow of anomalously viscous liquids in tubes," Inzh.-Fiz. Zh., 37, 239 (1979).
2. A. I. Mumladze, Yu. G. Nazmeev, and O. V. Maminov, "Determination of the hydraulic resistance and boundaries of flow regimes of a viscous liquid in tubes with vortex-forming strips," Izv. Vyssh. Uchebn. Zaved., Neft' Gas, No. 11, 59 (1982).
3. V. B. Litvinov, "Flow of polymers in rectangular and elliptical channels," Prikl. Mekh., 4, No. 9, 22 (1968).
4. V. B. Litvinov and V. M. Goncharenko, "The flow of non-Newtonian liquid in conditions of nonuniform temperature distribution," Inzh.-Fiz. Zh., 8, 802 (1970).
5. S. G. Mikhlin, Numerical Realization of Variational Methods [in Russian], Nauka, Moscow (1966).
6. S. S. Kutateladze, Foundations of the Theory of Heat Exchange [in Russian], Atomizdat, Moscow (1979).
7. Yu. G. Nazmeev and A. I. Mumladze, "Heat exchange during nonisothermal flow of a structurally viscous liquid in a tube with striplike deflectors of the flow. Boundary conditions of the first kind," Inzh.-Fiz. Zh., 46, 862 (1984).

AXISYMMETRIC PROBLEM ON THE IMPREGNATION OF A HEATED FILLER BY A VISCOPLASTIC LIQUID

E. A. Kosachevskaya and V. M. Sidorova

UDC 532.546

This article examines the penetration of a viscoplastic liquid (binder) into a preheated porous cylindrical braid (filler) moving inside it.

The study [1] examined a production process involving the continuous impregnation of porous fillers. This process is common in the manufacture of many composite materials. Since the viscosity of the binders is often too great at room temperature and since there are serious technical problems with the use of high pressure gradients, it has been proposed that fluid resistance during filtration be reduced by preheating the filler. A

V. A. Steklov Mathematical Institute, Academy of Sciences of the USSR, Moscow. Donetsk State University.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 50, No. 4, pp. 617-620, April, 1986. Original article submitted February 18, 1985.

similarity solution was obtained to a two-dimensional problem concerning the impregnation of the band of filler moving at a constant velocity in the impregnating composition. The composition had the properties of a viscous Newtonian fluid.

The present article examines a similar problem concerning the impregnation of a cylindrical braid (filler) drawn through an impregnation chamber containing a viscoplastic liquid (a polymer melt, resin, etc.). The filtration of the liquid is described by the generalized Darcy's law [2]

$$v_r = \begin{cases} -\dfrac{k}{\mu}\left(\dfrac{\partial p}{\partial r} - j\right) & \text{at } \left|\dfrac{\partial p}{\partial r}\right| > j, \\ 0 & \text{at } \left|\dfrac{\partial p}{\partial r}\right| \leqslant j. \end{cases} \tag{1}$$

The viscosity μ and the initial pressure gradient j are decreasing functions of temperature T:

$$\mu = \mu_f \varphi(\theta),\ j = j_f \psi(\theta),\ \theta = \frac{T - T_f}{T_0 - T_f}. \tag{2}$$

We assume for a filler with fine pores that the temperatures of the solid and liquid phases at each point of its impregnated part are the same and the velocity of the liquid in the x direction coincides with the pulling velocity. Given a medium with a sufficiently high thermal conductivity and a low filtration velocity, we can assume that at any moment of time there is a steady-state temperature distribution satisfying the Laplace equation. The solution of this equation satisfying the boundary conditions

$$\theta(x, R) = 0,\ \theta(x, R - \delta) = 1 \tag{3}$$

has the form

$$\theta(x, r) = \frac{\ln \dfrac{r}{R}}{\ln\left(1 - \dfrac{\delta}{R}\right)}. \tag{4}$$

The coordinate of the impregnation front δ is related to the filtration velocity by the equation

$$v_r = -\varepsilon u \delta'(x). \tag{5}$$

The continuity equation for an incompressible liquid leads to the equation

$$v_r = -\frac{c(x)}{r}. \tag{6}$$

In accordance with Eq. (5), at $r = R - \delta$, we find that

$$c(x) = \varepsilon u (R - \delta)\delta'. \tag{7}$$

Integrating Eq. (1) over r and allowing for (2), (3), (6), and the boundary conditions

$$p(x, R) = p_f + p_c,\ p(x, R - \delta) = p_0 \tag{8}$$

we have

$$\frac{\mu_f}{k} c(x) \int_R^{R-\delta} \frac{\varphi(\theta)}{r} dr + j_f \int_R^{R-\delta} \psi(\theta)\, dr = -\Delta p, \tag{9}$$

where $\Delta p = p_f + p_c - p_0$, p_c is the capillary pressure. Changing over to the variable θ in Eq. (9) and assuming that $1 - \delta/R = y$, we obtain

$$c(x) = -\frac{k}{\mu^*}\Delta p\left[1 + \frac{j_f R}{\Delta p} F(y)\right], \tag{10}$$

where $\mu^* = \mu_f \ln y \int_0^1 \phi\, d\theta$; $F(y) = \ln y \int_0^1 \psi y^\theta\, d\theta$.

We use Eqs. (7) and (10) to find the expression for the length of the working section

$$L = -\frac{R}{\alpha}\int_0^1 \frac{y \ln y\, dy}{1 + \beta F(y)}, \tag{11}$$

where $\alpha = (k\Delta p)/(\varepsilon u R \mu^*)$; $\beta = (j_f R)/\Delta p$.

To determine μ^* and $F(y)$, it is necessary to assign the functions $\varphi(\theta)$ and $\psi(\theta)$. The most general dependence of viscosity on temperature has the form [3]

$$\mu = A \exp\left(\frac{B}{T}\right), \tag{12}$$

where A is a slowly changing function of temperature which can be considered constant. It follows from this that

$$\varphi(\theta) = \exp\left\{B\left[\frac{1}{T_f + \theta(T_0 - T_f)} - \frac{1}{T_f}\right]\right\}. \tag{13}$$

We have the following expression for the characteristic "activation temperature" B

$$B = \frac{T_f T_0}{T_0 - T_f} \ln \frac{\mu_f}{\mu_0}. \tag{14}$$

With a small relative temperature difference $(T_0 - T_f)/T_f \ll 1$, Eq. (13) takes the form

$$\varphi(\theta) = \exp(-m\theta),\ m = \ln \frac{\mu_f}{\mu_0}, \tag{15}$$

and, finally, at $m \ll 1$

$$\varphi(\theta) = 1 - m\theta,\ m = 1 - \frac{\mu_0}{\mu_f}. \tag{16}$$

The values of μ^* corresponding to Eqs. (13), (15), and (16), respectively, are equal to:

$$\mu^* = \mu_f \frac{B}{T_0 - T_f} \exp\left(-\frac{B}{T_f}\right)\left[\frac{T_0}{B} \exp\left(\frac{B}{T_0}\right) - \frac{T_f}{B} \exp\left(\frac{B}{T_f}\right) + \mathrm{Ei}\left(\frac{B}{T_0}\right) - \mathrm{Ei}\left(\frac{B}{T_f}\right)\right], \tag{17}$$

$$\mathrm{Ei}(x) = \int_{-\infty}^{x} \frac{\exp(t)}{t}\, dt,$$

$$\mu^* = \frac{\mu_f}{m}[1 - \exp(-m)], \tag{18}$$

$$\mu^* = \frac{1}{2}(\mu_0 + \mu_f). \tag{19}$$

Taking the same temperature dependences for the initial pressure gradient, we find the expression for $F(y)$:

$$F(y) = \exp\left(-\frac{D}{T_f}\right) \int_0^1 y^\theta \exp\left[\frac{D}{T_f + \theta(T_0 - T_f)}\right] d\theta, \tag{20}$$

$$F(y) = \frac{y \exp(-n) - 1}{\ln y - n},\ n = \ln \frac{j_f}{j_0}, \tag{21}$$

$$F(y) = \frac{1}{\ln y}\left[y - 1 - n\left(y - \frac{y-1}{\ln y}\right)\right],\ n = 1 - \frac{j_0}{j_f}. \tag{22}$$

Here, D is the "activation temperature," determined from an equation similar to (14):

$$D = \frac{T_f T_0}{T_0 - T_f} \ln \frac{j_f}{j_0}.$$

We use Eqs. (19), (22), and (11) with the condition $\beta \ll 1$ to obtain the following expression of the length of the working section of the unit for linear relations $\varphi(\theta)$ and $\psi(\theta)$

$$L = \frac{R}{4\alpha}\left(1 + \frac{5 - 2n}{9}\beta\right). \tag{23}$$

Thus, the length over which impregnation occurs is directly proportional to the pulling velocity and inversely proportional to the pressure difference. The number $R\beta(5-2n)/36\alpha$ characterizes the increase in this length due to the initial pressure gradient.

NOTATION

v_r, radial filtration velocity; u, R, k, and ε, pulling velocity, radius, permeability, and porosity of the cylindrical filler; p_f, p_0, pressure of the liquid at the boundary with the filler and air pressure in its pores; T_f, T_0, corresponding temperatures; μ_f, μ_0, viscosities of the liquid at the temperatures T_f and T_0; j_f and j_0, initial pressure gradients at these temperatures: δ, thickness of the impregnated part of the filler.

LITERATURE CITED

1. Yu. A. Buevich and V. A. Kalinnikov, "Impregnation of a heated filler with a viscous liquid," Inzh.-Fiz. Zh., 36, No. 6, 997-1004 (1979).
2. A. Kh. Mirzadzhanzade, Problems of the Fluid Dynamics of Viscoplastic and Viscous Liquids and Applications in Oil Recovery [in Russian], Aznefteizdat, Baku (1959).
3. J. I. Frenkel, Kinetic Theory of Liquids, Peter Smith (1972).

EMISSIVITY OF STEELS AND ALLOYS IN THE SPECTRAL REGION 2-13 μm

V. A. Zaitsev, I. V. Gorbatenko, and M. A. Taimarov

UDC 536.3

The spectral emissivity of steels and alloys in the temperature range 700-900°K is experimentally studied.

Data on the spectral emissivity of structural materials is used as the initial data in present methods of calculating radiative heat transfer. Due to the complexity of the experiments and the great range of materials, such data is available only for a small number of grades.

Here we experimentally study the normal spectral emissivity of steels and alloys 40Kh2N-2MA, 38KhN3MA, 12Kh1MF, ÉP-182, 08Kh18N10T, St3sp, ÉI-712, 09G2S, steel 20, 1Kh18N10T, and D16AT during heating in air.

The experimental unit was based on an IKS-14A spectrophotometer operated in the double-beam mode. A diagram of the unit is shown in Fig. 1. The flow of heat radiation from the test material 8 was directed into the specimen channel, while the radiative heat flow from a thin-walled cylindrical model of a blackbody was directed into the comparison channel. The specimen and model were heated by an electric furnace 4. The temperatures of the radiating cavity of the blackbody and specimen were measured with Chromel—Alumel thermocouples with a thermoelectrode diameter of 0.2 mm. The readings of the thermocouples were calibrated with a standard PR-30/6 thermocouple. Additional measurements of the temperature of the radiating cavity of the blackbody were obtained with a TERA-50 radiation pyrometer. The thermo-emf was recorded with VK2-20 digital electronic voltammeters and an R363-2 dc potentiometer of accuracy class 0.002. To reliably measure the specimen temperature, the thermocouples were either caulked into the specimen or welded to it so that the surface of the thermocouple junction was flush with the radiating surface of the specimen.

The optical system of the IKS-14A spectrophotometer, including the double-beam light source, was left unchanged. This allowed us to better adjust and check the monochromator and the recording part of the instrument before the tests. During final adjustment of the unit, the heat flows in both channels were equalized by recording the radiation from a second, graphite model of a blackbody. When the temperatures of the blackbody models in the first and second channels were equal, the measured flows of heat radiation for these channels were also equal and the recorder of the spectrophotometer showed 100% transmission.

Belgograd Power Machinery Plant. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 50, No. 4, pp. 620-625, April, 1986. Original article submitted March 4, 1985.

0022-0841/86/5004-0441 $12.50