EFFECT OF FREE CONVECTION ON THERMODIFFUSION IN A LIQUID MIXTURE FILLING AN INCLINED RECTANGULAR CAVITY

K. R. Kostarev and A. F. Pshenichnikov

UDC 536.25

The convective motion which develops in an inclined cavity upon heating from above determines to a significant degree the form of the concentration field produced by thermodiffusion. The interaction of convective and thermodiffusion fluxes at small thermal Grashof numbers Gr causes the appearance of longitudinal jumps in concentration. Increase in temperature difference intensifies convection and encourages reduction in concentration gradients. The dominant role of convection for fixed Gr is determined by the angle of inclination of the liquid layer [1, 2]. A significant feature of liquid solutions is their low diffusion coefficient and thus high Schmidt number. This fact does not permit use of results obtained for gas mixtures, and greatly complicates numerical simulations. In contrast to [2], the present study will investigate thermodiffusion separation in a cavity with impermeable boundaries.

The rectangular cavity considered (Fig. 1, $T_2 > T_1$) was a gap between planar brass heat exchangers formed by use of two Plexiglas inserts a = 2.0 mm thick. The distance be- the inserts was 30.0 mm. On the endfaces the gap was closed by two plane semitransparent mirrors. The mirrors were set parallel to each other using alignment screws, forming the working space of a two-mirror autocollimation interferometer, which allowed study of concentration fields [3, 4]. The distance between mirrors was 30.3 mm. Interferograms obtained under isothermal conditions depicted lines of equal concentration. The transition from one interference band to the next corresponded to a change in concentration of the working solution (solution of sodium sulfate in water) of $3.4 \cdot 10^{-3}$%. The apparatus was equipped with a device which allowed changing its angle to the horizontal over the range of −15 to 60°, the axis of rotation being perpendicular to the plane of the mirrors. The amount of inclination was determined with an optical quadrant with scale divisions of 30".

The temperature of the heat exchangers was controlled by two jet-type ultrathermostats, provided with additional temperature stabilization systems. Temperature change was measured by a copper–Constantin differential thermocouple, connected to a type Shch-300 digital voltmeter. A mercury thermometer with scale divisions of 0.1°K was used to measure the temperature of the surrounding medium.

The working liquids used were 6.62% and 15.7% aqueous solutions of sodium sulfate, which differ from solutions of other salts in their high Soret coefficient and low diffusion coefficient [5]. This latter fact permits their use in study of concentration fields by the following technique. At the beginning of the experiment the model is oriented at some angle to the horizontal. The heat exchangers are connected to the thermostats. Under the action of the temperature difference convection develops in the cavity, and after the passage of some time (about 1.5 h) a steady-state concentration field is established. The time required for formation of a steady state temperature field did not exceed 6 min.

Before measuring concentration changes both heat exchangers were connected to the cold thermostat, thermal convection was halted, and the slow process of equalization of concentration perturbations began, mainly because of diffusion. Because the temperature perturbation relaxation time is two-three orders of magnitude less than the concentration perturbation relaxation time, the equalization takes place under isothermal conditions (temperature differential did not exceed 0.05°K). Interferograms obtained under these conditions were used to track the changes in the concentration field, and its parameters, corresponding to the initial steady-state regime, were calculated. To do this the experimentally obtained depend-

Perm'. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 73-76, September-October, 1986. Original article submitted August 8, 1985.

0021-8944/86/2705-0695$12.50

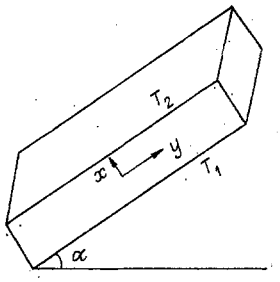

Fig. 1

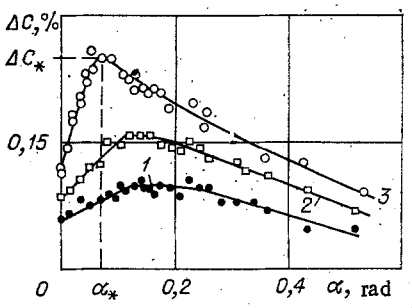

Fig. 2

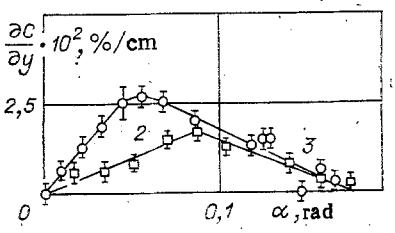

Fig. 3

ences of the parameters on time were approximated by expressions of the form $F(t) = F_0 \exp \times (-bt) + c$, where F_0 was the value of the parameter under consideration at the initial moment (i.e., in the steady-state regime). The quantities F_0, b, and c were determined from experimental curves. The parameters chosen to characterize the concentration field were the longitudinal and transverse components of the concentration gradient at the center of the cavity and the concentration change ΔC between the lowermost and uppermost points of the inclined cavity.

Figure 2 shows the dependence of the concentration change ΔC on cavity angle α for various $Gr = g\beta_1 \Delta T a^3/\nu^2$, where g is the acceleration of gravity, ΔT is the decrease in temperature of the heat exchanger, $\beta_1 = -1/\rho(\partial\rho/\partial T)$; ν are thermal expansion and kinematic viscosity coefficients. Curves 1-3 correspond to Gr = 17, 25, 36. The mean solution concentration over volume $C_0 = 15.7\%$. As is evident from Fig. 2, the separation ΔC has a clearly expressed maximum at $\alpha = \alpha_*(Gr)$. We note that the concentration change ΔC_* in the inclined cavity increases with increase in temperature difference significantly more rapidly than in a horizontal cavity, where convective motion is absent.

For Gr = 36, the concentration distribution along the axis was studied. It developed that at angles of inclination less than α_* this distribution is close to linear.

Figures 3 and 4 show the dependence of longitudinal and transverse components of the concentration gradient at the center of the cavity on angle of inclination. Curves 1-3 correspond to Gr = 17, 25, 36. The longitudinal component of the gradient has a maximum at approximately the same angles of inclination as the quantity ΔC. Thus, for Gr = 36, the angles of inclination of the cavity corresponding to maxima in the curves $\Delta C = \Delta C(\alpha)$ and $\partial C/\partial y = f_1(\alpha)$ coincide, while for Gr = 25 they are equal to 0.13 and 0.09 rad. The transverse component of the concentration gradient decreases monotonically with increase in inclination. Knowing the dependence $\partial C/\partial x = f_2(\alpha)$, we can find its value at $\alpha = 0$ (i.e., in a convection-free position) and determine the Soret coefficient S with the known expression

$$\partial C/\partial x = SC_0(1 - C_0)\partial T/\partial x,$$

where C_0 is the mean concentration over the volume. In the present experiments the value of the Soret coefficient calculated in this manner proved equal to $(8.7 \pm 0.3)\cdot 10^{-3}$ K^{-1}, which coincides with the results of [5] and indicates the good quality of the equipment.

In a numerical simulation of thermodiffusion convection in an inclined cavity, [1] established that the structure of the flows produced at various Gr, but identical values of the parameter αGr, are practically identical. The longitudinal component of the concentration gradient reaches a maximum at Gr and α corresponding to some fixed value of the complex

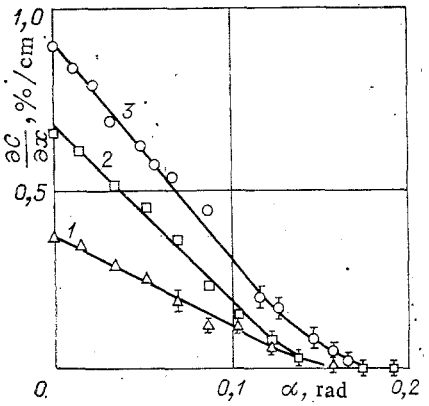

Fig. 4

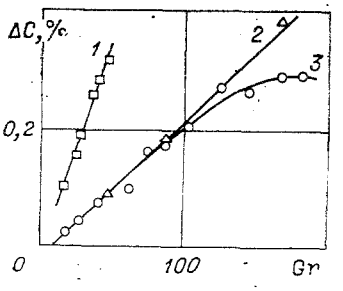

Fig. 5

$$\mathrm{Gr}\sin\alpha(1+\varepsilon)\,\mathrm{Sc} = K_{*}. \qquad (1)$$

where $\varepsilon = S(1 - C_0)C_0\beta_2/\beta_1$ is the dimensionless thermodiffusion parameter; Sc is the Schmidt number; $\beta_2 = 1/\rho(\partial\rho/\partial C)$, D are the concentration expansion and diffusion coefficients. It can be proposed that Eq. (1) also defines the conditions under which the maximum concentration separation $\Delta C = \Delta C_*$ occurs. The experiments performed in the present study indicate the validity of this proposition for the region $\mathrm{Gr} \leq 130$. The value of the complex found for various temperature heads and solution concentrations was equal to $K_* = (2.0 \pm 0.2)\cdot 10^4$.

Figure 5 shows the dependence of maximum concentration separation $\Delta C_* = \Delta C(\alpha_*, \mathrm{Gr})$ on Gr for $C_0 = 6.62\%$ (curve 2). Curve 3 is the concentration differential for angles of inclination, as calculated with Eq. (1). It is evident that for $\mathrm{Gr} \leq 130$ these curves coincide, which confirms the proposition suggested above. The function $\Delta C_* = f(\mathrm{Gr})$ is linear over the entire Gr range studied. Curve 1 is for a mean concentration $C_0 = 15.7\%$. The slope of the curve increases with increase in the dimensionless thermodiffusion parameter, which determines the value of the concentration differential.

In conclusion, the authors thank G. Z. Gershun for evaluation of the results and helpful remarks.

LITERATURE CITED

1. A. Yu. Pinyagin and A. F. Pshenichnikov, "Free convection of a binary liquid mixture an inclined rectangular cavity," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 4 (1979).
2. P. L. Chueh and H. M. Yeh, "Thermal diffusion in plate column inclined for improved performance," AIChE J., 13, No. 1 (1967).
3. S. E. Gustafson and Rolf A. E. Kjellander, "An interferometer for direct recording of refractive index distributions," Z. Naturforsch., 23a, No. 2 (1968).
4. K. G. Kostarev and A. F. Pshenichnikov, Experimental Study of Concentration Fields in the Gap between Horizontal Coaxial Cylinders under Free Laminar Convection Conditions [in Russian], Permsk. Inst., Perm' (deposited in VINITI Dec. 11, 1984, No. 7906-84).
5. V. M. Buzmakov, A. Yu. Pinyagin, and A. F. Pshenichnikov, "Method for simultaneous measurement of Soret coefficient and diffusion of liquid solutions," Inzh. Fiz. Zh., 44 (1983).