ABSTRACTS OF ARTICLES DEPOSTED AT VINITI*

EFFECTS OF HEAT-TRANSFER FACTOR ON THE CHARACTERISTICS OF STRAIGHT FINS

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UDC 536.244

Published relationships for heat transfer at straight fins of constant cross section have been derived subject to the condition that the heat-transfer coefficient is constant over the surface; this is reasonably correct for fins whose performance factor is close to unity, but for inefficient fins the heat-transfer coefficient varies considerably on account of the temperature variation over the height of the fin. If this is neglected, the calculated heat transfer may differ from the real case.

To determine the errors that can occur in the design of heat-transfer devices we have examined the heat transfer from straight fins of constant cross section on the basis of variation in the heat-transfer coefficient along the fin.

The variation in the excess temperature along a fin is represented as the differential equation

$$\frac{d^2\theta}{dx^2} = n_1\theta^2 + n_2\theta, \tag{1}$$

where n_1 and n_2 are quantities dependent on the heat-transfer conditions, while θ is the excess temperature in degrees at a distance x from the base.

The solution to (1) is obtained as a Maclaurin series:

$$\theta(x) = \theta(0) + \frac{x}{1}\theta'(0) + \frac{x^2}{2!}\theta''(0) + \frac{x^3}{3!}\theta'''(0) + \frac{x^4}{4!}\theta^{\mathrm{IV}}(0) + \cdots \tag{2}$$

We assume that $\theta = \theta_{st}$ at $x = 0$, and get after replacing the derivatives that

$$\begin{aligned} \theta = \theta_{st} \pm x \sqrt{\frac{2}{3} n_1(\theta_{st}^3 - \theta_h^3) + n_2(\theta_{st}^2 - \theta_h^2)} + \frac{x^2}{2!}(n_1\theta_{st} + n_2)\theta_{st} \pm \\ \pm \frac{x^3}{3!}(2n_1\theta_{st} + n_2)\sqrt{\frac{2}{3} n_1(\theta_{st}^3 - \theta_h^3) + n_2(\theta_{st}^2 - \theta_h^2)} + \\ + \frac{x^4}{4!}\Bigl\{2n_1\Bigl[\frac{2}{3} n_1(\theta_{st}^3 - \theta_h^3) + n_2(\theta_{st}^2 - \theta_h^2) + (n_1\theta_{st} + n_2)\theta_{st}^2\Bigr] + \\ + n_2\theta_{st}(n_1\theta_{st} + n_2)\Bigr\} \pm \ldots, \end{aligned} \tag{3}$$

where θ_{st} and θ_h are the excess temperatures at the base and at the end of the fin, both in degrees.

The excess temperature at the end of the fin is given by (3) with $x = h$.

The heat dissipated by the fin is determined from the condition that the heat lost is equal to the heat coming into the base:

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 2, pp. 358-364, August, 1975.

$$Q = -\lambda f\left(\frac{d\theta}{dx}\right)_{x=0} = \pm\lambda f\sqrt{\frac{2}{3}n_1(\theta_{\mathrm{st}}^3-\theta_h^3)+n_2(\theta_{\mathrm{st}}^2-\theta_h^2)}; \tag{4}$$

where λ is the thermal conductivity in W/m·deg and f is the area in m^2 of the base perpendicular to the heat flow.

We have used these relationships to examine the cooling of a straight fin with a laminar flow of air with free convection; the range in θ was 20-130° for $l \leq 1$ m.

The calculations for this case showed that low values were obtained if the heat-transfer factor was assumed to be constant; this was particularly so for low-performance fins. If the performance factor was 0.3, calculations from formulas neglecting variation in the factor reduced the result by about 9%.

If the performance factor was over 0.6, which is most characteristic of heating plants, the error did not exceed 4%, so the error can usually be neglected for simple cases and the ordinary formulas can be applied without considering the variation in the heat-transfer factor.

Dep. 712-75, January 13, 1975. Original article submitted June 24, 1974.

MECHANICS OF A PHASE INTERFACE

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UDC 532.6+541.12.012.6

Comparison has been made of two differential equations for **the interphase region** between the one-component liquid and the vapor or a solid and the vapor, using the potential ψ of the intermolecular forces (linear case, equilibrium or stationary state):

$$\psi_x'' - \psi/\lambda^2 = 4\pi k\rho(x), \tag{1}$$

$$\psi_x'' + \psi_x'/\lambda = 4\pi k\rho(x)\exp\left(\mp\frac{x}{\lambda}\right);\quad \begin{array}{l} x<0:\ «+», \\ x>0:\ «-». \end{array} \tag{2}$$

Equations (1) and (2) are based on interactions of the following form:

$$F = km_1m_2\left[\frac{1}{R^2}+\frac{\exp\left(-\frac{R}{\lambda}\right)}{3\lambda^2}\right], \tag{3}$$

$$F = km_1m_2\frac{1}{R}\left(\frac{1}{R}+\frac{1}{\lambda}\right)\exp\left(-\frac{R}{\lambda}\right), \tag{4}$$

where the point masses m_1 and m_2 are effective (conditional) quantities; the volumes of these, and the distance R between them, are much less than the volumes of real molecules or atoms and the mean distance between such particles. It is found that (2) describes ψ more closely. Variational methods ($\delta\sigma = 0$) give $\rho = \rho(x)$ (see, for example, [1]) and $\psi = \psi(x)$:

$$\psi = -4\pi k\lambda^2\rho(x). \tag{5}$$

In the case of (1) $\rho = \rho(x)$ may have a solely linear result.

A more complex case has also been considered, namely, a two-component solution, with the solute a surfactant (solutions of O, N, and S in molten iron). Figure 1 shows curves for the solvent ρ_s and impurity ρ_i, and also for the forces F_s and F_i acting on the substances. These indicate the conditions under which the problem may be solved. We assume that the boundary points for the interphase region virtually coincide for the two substances.

As a result we have (equilibrium, stationary state): region II; $\delta\sigma_2 = 0$

$$\rho_i(x) = \rho_{i,2} - (\rho_{i,2}-\rho_{i,3})\frac{x}{l_2} + \frac{\lambda_\varepsilon\sqrt{2}}{l_3}(\rho_{i,2}-\rho_{i,3})\sin\frac{x}{\lambda_\varepsilon\sqrt{2}};\quad \frac{l_2}{\lambda_\varepsilon} = 2\pi\sqrt{2}, \tag{6}$$

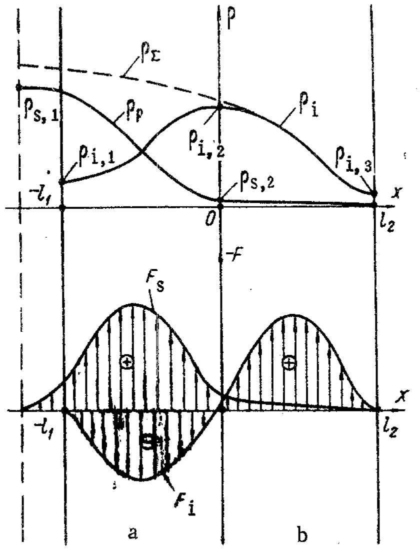

Fig. 1. Curves for the concentration (top) and forces acting on the solute in the interphase region (equilibrium). The broken vertical line on the left is the boundary of the region with respect to the solvent, i.e., for the case where this boundary does not coincide for the two substances: a) surface layer of liquid phase (region I); b) surface layer of gas phase (region II).

$$\psi_i = -4\pi k_\varepsilon \lambda_\varepsilon^2 \rho_i(x); \tag{7}$$

region I; $\delta\sigma_1 = 0$

$$\rho_S(x) = -\rho_{S,1}\frac{x}{l_1} + \frac{\rho_{p,1}\alpha\sqrt{2}}{\lambda_1}\sin\left(\frac{l_1}{\alpha\sqrt{2}} + \frac{x}{\alpha\sqrt{2}}\right); \ \frac{\lambda_1}{\alpha} = 2\pi\sqrt{2}, \tag{8}$$

$$\rho_i(x) = \rho_{i,2} - (\rho_{i,1} - \rho_{i,2})\frac{x}{l_1} + \rho_{i,1}\frac{\alpha\sqrt{2}}{l_1}\sin\left(\frac{l_1}{\alpha\sqrt{2}} + \frac{x}{\alpha\sqrt{2}}\right), \tag{9}$$

$$\psi_{S,1} = -4\pi k_{\varepsilon,S} \lambda_{\varepsilon,S}^2 \rho_S(x); \ \psi_{i,1} = +4\pi k_{\varepsilon,i} \lambda_{\varepsilon,i}^2 \rho_i(x). \tag{10}$$

For the surface tension

$$\sigma = \sigma_1 + \sigma_2 = 4\pi\frac{k_\varepsilon}{l_2}\lambda_\varepsilon^4(\rho_{i,2} - \rho_{i,3})^2 + \frac{4\pi\beta}{l_1}(\rho_{i,2} - \rho_{i,1})^2 + \frac{4\pi\beta}{l_1}\rho_{S,1}^2 + \frac{8\pi\beta}{l_1}\rho_{S,1}(\rho_{i,1} - \rho_{i,2}). \tag{11}$$

The quantity $\rho_{i,2}$ may be determined from the condition $\partial\sigma/\partial\rho_{i,2} = 0$, and also by using the adsorption Γ_i as found by experiment:

$$\rho_{i,2} = \frac{\Gamma_i}{\Delta L} + \frac{l_1\rho_{i,1} + l_2\rho_{i,3}}{2\Delta L}. \tag{12}$$

A test has been made on (11) for the simplest case, and the results were satisfactory.

NOTATION

λ, λ_ε, $\lambda_{\varepsilon,i}$, and $\lambda_{\varepsilon,S}$, screening constants; k, k_ε, $k_{\varepsilon,S}$, and $k_{\varepsilon,i}$, constants representing the interaction of the effective point masses; α and β, functions of the previous quantities; σ, surface tension; $\Delta L = l_1 + l_2$, thickness of surface layer; F, interaction force between m_1 and m_2; $\rho(x)$, density, $\rho_\Sigma = \rho_S + \rho_i$.

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Dep. 713-75, January 14, 1975. Original article submitted July 24, 1974.

TEMPERATURE DISTRIBUTIONS IN LAYERED BODIES

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UDC 517.946

A one-sided bounded stratified body

$$\Pi^- = \{(x, z), -\infty < x \leqslant a, 0 < z \leqslant l\}$$

with continuously distributed heat sources, whose density is $f^{(1)}(x, z, t)$, and whose temperature $\psi^{(1)}(x, z)$ begins to propagate with speed $\varphi^{(1)}(x, z)$, is brought into contact with a one-sided bounded stratified body

$$\Pi^+ = \{(x, z), a \leqslant x < +\infty, 0 \leqslant z \leqslant l\}$$

with continuously distributed heat sources, whose density is $f^{(2)}(x, z, t)$, and whose temperature $\psi^{(2)}(x, z)$ begins to propagate with speed $\varphi^{(2)}(x, z)$. The heat-wave propagation speeds in the two bodies are finite.

If we denote the temperatures of the bodies by $u^{(i)}(x, z, t)(i = 1, 2)$, then the termination of the temperature distributions amounts to solving the following: find a bounded solution to the following system of equations [1]:

$$b_1^2 \frac{\partial^2 u^{(1)}}{\partial t^2} + c_1^2 \frac{\partial u^{(1)}}{\partial t} - a_1^2 \left(\frac{\partial^2 u^{(1)}}{\partial x^2} + \frac{\partial^2 u^{(1)}}{\partial z^2} \right) = f^{(1)}(x, z, t) \tag{1}$$

$$(0 \leqslant t \leqslant T,\ (x, z) \in \Pi^-),$$

$$b_2^2 \frac{\partial^2 u^{(2)}}{\partial t^2} + c_2^2 \frac{\partial u^{(2)}}{\partial t} - a_2^2 \left(\frac{\partial^2 u^{(2)}}{\partial x^2} + \frac{\partial^2 u^{(2)}}{\partial z^2} \right) = f^{(2)}(x, z, t) \tag{2}$$

$$(0 \leqslant t \leqslant T,\ (x, z) \in \Pi^+),$$

that satisfy the conditions

$$u^{(1)}\Big|_{t=0} = \psi^{(1)}(x, z), \quad \frac{\partial u^{(1)}}{\partial t}\Big|_{t=0} = \varphi^{(1)}(x, z) \quad (x, z) \in \Pi^-, \tag{3}$$

$$u^{(2)}\Big|_{t=0} = \psi^{(2)}(x, z), \quad \frac{\partial u^{(2)}}{\partial t}\Big|_{t=0} = \varphi^{(2)}(x, z) \quad (x, z) \in \Pi^+, \tag{4}$$

$$u^{(1)}|_{x=a} = u^{(2)}|_{x=a}, \ k_1 \frac{\partial u^{(1)}}{\partial x}\Big|_{x=a} = k_2 \frac{\partial u^{(2)}}{\partial x}\Big|_{x=a}, \tag{5}$$

$$u^{(i)}|_{z=0} = 0, \ u^{(i)}|_{z=l} = 0 \quad (i = 1,2). \tag{6}$$

An approximate analytical solution has been constructed by the straight-line z method and Laplace integral transformation with respect to t.

In particular, for $c_1 \to 0$ and $c_2 \to 0$ an approximately pure wave-temperature distribution is obtained, while for $b_1 \to 0$ and $b_2 \to 0$ one gets an approximately ordinary (parabolic) temperature distribution in a two-layer body. The latter coincides with a standard result [5].

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Dep. 715-75, January 24, 1975. Original article submitted March 19, 1974.

A METHOD OF MEASURING THE BULK SPECIFIC HEAT OF A SOLID OR POWDER AS A FUNCTION OF TEMPERATURE

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UDC 536.21

The temperature distribution in a semiinfinite body of initial temperature T_0 is derived for the case where the surface temperature suddenly rises to T_s and subsequently remains constant; this is described by a generalized curve in the coordinates temperature T and parameter $z = x/2\sqrt{\tau}$, where x is a distance of a point from the surface and τ is the time from the onset of heating.

We split up the range from T_s to T_0 into m arbitrary sections and assume that within each section the specific bulk heat capacity is linearly dependent on temperature; then the actual temperature dependence of the specific heat is replaced by a broken line, which can approximate the true curve as closely as may be desired.

Then simple transformations give an expression for the mean specific heats $C_c\ (T_i)$ in the range from T_0 to T_i:

$$C_c(T_i) = \left\{ \frac{Q_i}{2\sqrt{\tau}} - \sum_{k=1}^{i-1} \int_{T_{k-1}}^{T_k} \frac{(T-T_0)[C_c(T_{k-1})(T_k-T)+C_c(T_k)(T-T_{k-1})]}{-\left(\frac{dT}{dz}\right)(T_k-T_{k-1})}\, dT - C_c(T_{i-1}) \int_{T_{i-1}}^{T_i} \frac{(T-T_0)(T_i-T)}{-\left(\frac{dT}{dz}\right)(T_i-T_{i-1})}\, dT \right\} : \int_{T_{i-1}}^{T_i} \frac{(T-T_0)(T-T_{i-1})}{-\left(\frac{dT}{dz}\right)(T_i-T_{i-1})}\, dT, \qquad (1)$$

where Q_i and (dt/dz) are, respectively, the amount of heat absorbed by unit surface in time τ and the derivative of the T vs z curve constructed for the case where the surface is maintained at a constant temperature T_i. The generalized T vs z curves for each T_i have been constructed from the readings of 6-8 thermocouples set up within the specimens. The bulk specific heat of the material at room temperature may be derived from published data or by any standard method.

The mean specific heats given by (1) are used to derive the true specific heats from

$$C(T_i) = \frac{2C_c(T_i)(T_i-T_0) - \sum_{k=1}^{i-1} [C(T_k)+C(T_{k-1})](T_k-T_{k-1})}{T_i-T_{i-1}} - C(T_{i-1}), \qquad (2)$$

where $C(T_i)$, $C(T_k)$, $C(T_{k-1})$ are true values for the bulk specific heat at the corresponding temperatures.

The accuracy of the C(T) calculations was checked by computer means; it was found that the overall error from replacing the true curve by a broken line did not exceed 5-10%, nor did the error of calculation.

The method gives a fairly simple and reliable means of determining the bulk specific heat as a function of temperature; in particular, it can be used to determine the temperature dependence of the specific heat for moulding sands.

Dep. 709-75, January 13, 1975. Original article submitted December 25, 1972.

SPEED OF A GAS OR LIQUID BUBBLES IN A LIQUID-FILLED TUBE

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UDC 532.529.5

Measurements made on vertical glass tubes of various diameters and lengths 1.2-1.5 m on air bubbles in various liquids and bubbles of liquids in liquids have been used with data from other sources to derive a general relationship for such motion:

$$w = up\left[\frac{gD_t\,(\rho' - \rho'')}{\rho_i}\right]^{1/2}, \tag{1}$$

where

$$p = \left[1 - \left(0.61 + \frac{0.39}{1.084^{(\mathrm{We}-4)}}\right)^2\right]\left[0.61 + \frac{0.39}{1.084^{(\mathrm{We}-4)}}\right]^{1/2}.$$

Formula (1) has been derived from general assumptions, in particular, the relation between the speed in an unbounded volume and in a tube,

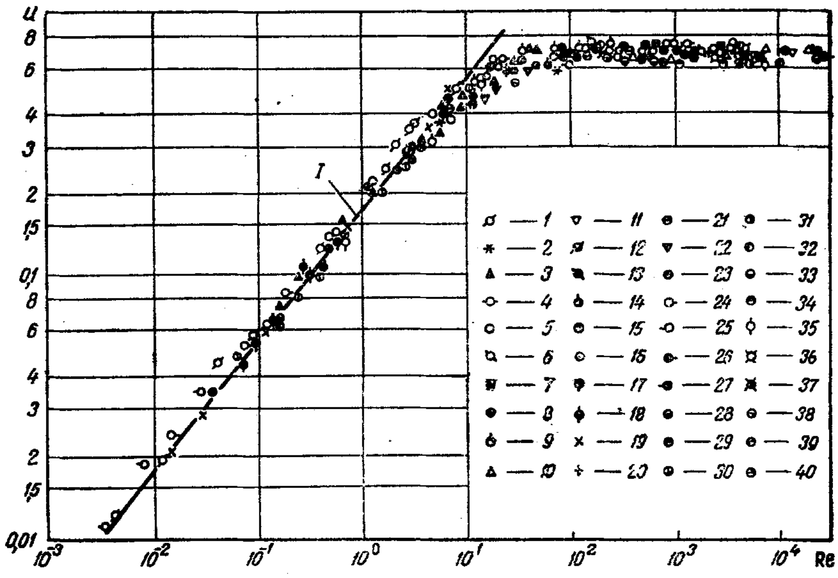

Fig. 1. The Re dependence of u. Our results for air in liquids: 1) Glycerol; 2) isoamyl alcohol; 3) TKP-22 oil; 4) isopropanol; 5) CCl_4; 8) water; 9) tetrabromoethane; water rising in: 6) CCl_4; CCl_4 falling in: 7) water. Data from White, Bedmore, Dumitrescu, Davis, Taylor, Griffiths, Wallis, and others: air in liquids: 10-13) water; 14) aqueous sugar solution; 15) Tellus oil; 16 and 17) glycol solution; 18) Voluta oil; 19) glycerol; 20) ethanol; 21) aqueous sugar solution; 22) ethylene glycol; 23 and 24) dilute sugar syrup; 25) sugar syrup; large air bubbles in liquids: 26) 40% acetic acid solution; 27) ethyl ether; 28) 27% ethyl acetate in cotton oil; 29) 40.9% ethyl acetate in cotton oil; 30) aniline; 31) methanol; 32) 10% acetic acid; 33) 31.1% acetic acid; 34) butanol; 35) ethyl acetate; 36) nitrobenzene; 37) pyridine; 38) 70% acetic acid; 39) isopropanol; 40) acetic acid. I) curve calculated from (1).

$$w = w_\infty \left[1 - \left(\frac{D}{D_t}\right)^2\right] \qquad (2)$$

and the empirical relationship

$$\frac{D}{D_t} = 0{,}61 + \frac{0{,}39}{1.084^{(\mathrm{We}-4)}} \, . \qquad (3)$$

It follows from (3) that for We → ∞ (tubes of large diameter) $D/D_t \simeq 0.61$, which corresponds to Dumitrescu's measurements. For We = 4, $D = D_t$, and neither rise of the bubble nor escape of the liquid from the open end will occur, which is in accordance with a theoretical solution due to Maxwell and Gibson and is confirmed by experiments by Duprets and others.

Figure 1 shows the data processed as $u = f(\mathrm{Re})$; it is clear that for $\mathrm{Re} > 100$; $\mathrm{We} > 60$; $[(\rho' - \rho'')/\rho_t]^{1/2} \simeq 1$, $u = 0.707$; $p = 0.49$ or $up = C = 0.345$.

Under these conditions (1) is identical with Dumitrescu's formula for the rate of rise in large tubes, and the latter is to be considered as a particular case of (1).

For $\mathrm{Re} < 2$, $u = 0.18\sqrt{\mathrm{Re}}$ or

$$\frac{4}{3u^2} = \zeta = \frac{41}{\mathrm{Re}} \, . \qquad (4)$$

In accordance with the Stokes solution, which applies for a sphere moving in a large volume, $\zeta = 24/\mathrm{Re}$; this value differs from (4) by a constant factor, which is due to the special features of a bubble rising in a tube.

The analysis indicates that there are no essential differences between liquid—liquid and liquid—gas systems, and that the two can simulate one another at least in the range of parameters used.

NOTATION

w, speed of drop or bubble relative to tube wall in immobile liquid, m/sec; w_∞, speed of large bubble (drop) in large volume, m/sec; D_t, internal diameter of tube, m; D, diameter of spherical drop (bubble), m; g, acceleration due to gravity, m/sec^2; C, coefficient; ρ', density of heavy phase, kg/m^3; ρ'', density of light phase, kg/m^3; ρ_i, density of surrounding medium, kg/m^3; ζ, hydraulic-resistance factor; $u = \sqrt{4/3\zeta}$; σ, surface tension, N/m; ν, kinematic viscosity of surrounding medium, m^2/sec; $\mathrm{We} = D_t^2 g(\rho' - \rho'')/\sigma$, Weber number; $\mathrm{Re} = wD_t/\nu$, Reynolds number.

Dep. 710-75, December 30, 1974. Original article submitted September 16, 1974.