# NOMENCLATURE

| | | |
|---|---|---|
| $b$ | – | channel width, m; |
| $c_f = 2\tau_w/\rho u^2$ | – | skin friction coefficient; |
| $c_p$ | – | specific heat, J/(kg·K); |
| $D$ | – | curvature diameter, m; |
| $d$ | – | diameter, m; |
| $d_1$, $d_2$ | – | wetted surface diameters of the tubes of annular or helical channel, m; |
| $d_e$ | – | equivalent diameter of the channels, m; |
| $E = (\overline{u'^2} + \overline{v'^2} + \overline{w'^2})/2$ | – | turbulence energy, $m^2/s^2$; |
| $F$ | – | flow section area, m; |
| $g$ | – | acceleration due to gravity, $m/s^2$; |
| $h$ | – | channel height, m; enthalpy, J/kg; |
| $h_* = q_w/\rho u_*$ | – | characteristic enthalpy, J/kg; |
| $K = (\nu/u^2)(du/dy)$ | – | acceleration parameter; |
| $K = \mathrm{Gr}_A/\mathrm{Re}^2$ | – | natural convection (bouyancy) parameter; |
| $l$ | – | channel length along the axial line; turbulence scale, m; |
| $l_+ = lu_*/\nu$ | – | dimensionless turbulence scale; |
| $l_t$ | – | thermal turbulence scale, m; |
| $P$, $p$ | – | pressure, Pa; |
| $q$ | – | heat flux density, $W/m^2$; |
| $q^+ = q_w/h\bar{u}\rho$ | – | heat flux parameter; |
| $R$ | – | curvature radius, m; |
| $r$ | – | current radius, m; |
| $r_o$ | – | tube radius, m; |
| $s$ | – | twist pitch of the channel, m; |
| $T$ | – | temperature, K; |
| $T_* = q_w/\rho c_p u_*$ | – | characteristic temperature, K; |
| $T^+ = (T_w - T)/T_*$ | – | dimensionless temperature; |
| $u$ | – | flow velocity, m/s; |

| | | |
|---|---|---|
| $u_* = \sqrt{\tau_w/\rho}$ | – | friction velocity, m/s; |
| $u^+ = u/u_*$ | – | dimensionless velocity; |
| $u, v, w$ | – | velocity components, m/s; |
| $\overline{u'v'_+} = -\overline{u'v'}/u_*^2$ | – | dimensionless turbulent shearing stresses; |
| $\overline{u'T'_+} = \overline{u'T'}/u_*T_*$ | – | dimensionless turbulent axial heat transfer; |
| $\overline{v'^2_+} = \overline{v'^2}/u_*^2$ | – | dimensionless intensity of radial velocity oscillations; |
| $v'T'_+ = -v'T'/u_*T_*$ | – | dimensionless turbulent radial heat transfer; |
| $x$ | – | longitudinal coordinate, distance from the heating origin, m; |
| $x_+ = xu_*/v$ | – | dimensionless longitudinal coordinate; |
| $y$ | – | transverse coordinate, m; |
| $y^+ = yu_*/\nu$ | – | dimensionless transverse coordinate; |
| $\alpha$ | – | heat transfer coefficient, $W/(m^2 \cdot K)$; |
| $\beta = -1/\rho(\partial\rho/\partial T)_p$ | – | volumetric expansion coefficient, 1/K; |
| $\Delta$ | – | maximal relative error; |
| $\delta$ | – | boundary layer thickness, wall thickness, m; relative rms error; |
| $\delta_{i,\alpha}$ | – | Kronnecker delta; |
| $\gamma$ | – | intermittence coefficient; |
| $\varepsilon = E^{3/2}/l$ | – | dissipation function; |
| $\varepsilon_t$ | – | thermal dissipation function; |
| $\varepsilon_\tau = -\overline{u'v'}/(du/dy)$ | – | turbulent viscosity, $m^2/s$; |
| $\varepsilon_q = -\overline{v'T'}/(dT/dy)$ | – | eddy diffusivity, $m^2/s$; |
| $\theta$ | – | angle of curvature, deg; |
| $\varkappa$ | – | universal constant; |
| $\lambda$ | – | thermal conductivity, $W/(m \cdot K)$; |
| $\mu$ | – | dynamic viscosity, Pa·s; |
| $\nu$ | – | kinematic viscosity, $m^2/s$; |
| $\xi$ | – | friction factor; |
| $\Pi$ | – | wetted perimeter of the channel, m; |
| $\rho$ | – | density, $kg/m^3$; |
| $\tau$ | – | shear stress, $N/m^2$; |
| $\varphi$ | – | angle, °, deg; |

$\psi = T_w / T_f$ – temperature factor;

$\mathrm{De} = \mathrm{Re}\sqrt{d/D}$ – Dean number;

$\mathrm{Gr}_q = g\beta q_w d^4 \rho^2 / \lambda \mu^2$ – Grashof number defined by the heat flux specified on the surface;

$\mathrm{Gr}_A = g\beta\, d^4 \left( \frac{dT_f}{dx} \right) \frac{1}{16\nu^2}$ – Grashof number defined by the longitudinal gradient of the bulk temperature of the liquid;

or $\mathrm{Gr}_A = \frac{\mathrm{Gr}_q}{4\mathrm{RePr}}$

$\mathrm{Nu} = \alpha d_e / \lambda$ – Nusselt number;

$\mathrm{Pr} = \mu c_p / \lambda$ – Prandtl number;

$\mathrm{Pr}_t = \varepsilon_\tau / \varepsilon_q$ – turbulent Prandtl number;

$\mathrm{Re} = \bar{u} d_e / \nu$ – Reynolds number;

$\mathrm{St} = \mathrm{Nu} / \mathrm{RePr}$ – Stanton number.

**Subscripts:**

$o$ – refers to a straight channel;

$1$ – inner tube;

$2$ – outer tube;

$\infty$ – in the external flow, in the stabilized flow region;

$cr$ – laminar-turbulent flow transition;

$cr1$ – beginning of transition;

$cr2$ – end of transition;

$f$ – in the flow;

$in$ – at the inlet;

$L$ – laminar;

$T$ – straight tube, turbulent;

$w$ – at the wall;

$\psi = 1$ – at constant physical properties;

$(\bar{\ })$ – averaging;

$(\,'\,)$ – oscillating component.

The remaining symbols are defined in the text.