NOMENCLATURE

\[ c_f = \frac{2 \tau_w}{\rho u^2} \]  
- 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;

\[ E = \frac{(u'^2 + v'^2 + w'^2)}{2} \]  
- turbulence energy, m²/s²;

\[ F \]  
- flow section area, m;

\[ g \]  
- acceleration due to gravity, m/s²;

\[ h \]  
- channel height, m; enthalpy, J/kg;

\[ h_* = \frac{q_w}{\rho u_*} \]  
- characteristic enthalpy, J/kg;

\[ K = \frac{(nu^2)(du/du)}{dy} \]  
- acceleration parameter;

\[ K = \frac{Gr_A}{Re^2} \]  
- natural convection (bouyancy) parameter;

\[ l \]  
- channel length along the axial line; turbulence scale, m;

\[ l_* = \frac{lu_*}{\nu} \]  
- dimensionless turbulence scale;

\[ l_t \]  
- thermal turbulence scale, m;

\[ P, p \]  
- pressure, Pa;

\[ q \]  
- heat flux density, W/m²;

\[ q^* = \frac{q_w}{\bar{h}u*} \]  
- 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;

\[ T_* = \frac{q_w}{\rho c_p u_*} \]  
- characteristic temperature, K;

\[ T^* = \frac{(T_w - T)}{T_*} \]  
- dimensionless temperature;

\[ u \]  
- flow velocity, m/s;
\[ u_* = \sqrt{\frac{\tau_w}{\rho}} \]  
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;

\[ v'T'_+ = -\overline{v'T'}/u_*T_* \]  
dimensionless turbulent radial heat transfer;

\[ x \]  
longitudinal coordinate, distance from the heating origin, m;

\[ x_+ = xu_*/v \]  
dimensionless longitudinal coordinate;

\[ y \]  
transverse coordinate, m;

\[ y^+ = yu_*/v \]  
dimensionless transverse coordinate;

\[ \alpha \]  
heat transfer coefficient, W/(m²·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;

\[ \delta_{i,\alpha} \]  
Kronecker delta;

\[ \gamma \]  
intermittence coefficient;

\[ \varepsilon = \varepsilon^{3/2}/l \]  
dissipation function;

\[ \varepsilon_i \]  
thermal dissipation function;

\[ \varepsilon_t = -\overline{u'v'/(du/dy)} \]  
turbulent viscosity, m²/s;

\[ \varepsilon_q = -\overline{v'T'/(dT/dy)} \]  
eddy diffusivity, m²/s;

\[ \theta \]  
angle of curvature, deg;

\[ \kappa \]  
universal constant;

\[ \lambda \]  
thermal conductivity, W/(m·K);

\[ \mu \]  
dynamic viscosity, Pa·s;

\[ \nu \]  
kinecatic viscosity, m²/s;

\[ \xi \]  
friction factor;

\[ \Pi \]  
wetted perimeter of the channel, m;

\[ \rho \]  
density, kg/m³;

\[ \tau \]  
shear stress, N/m²;

\[ \varphi \]  
angle, °, deg;
\[ \psi = \frac{T_w}{T_f} \quad \text{temperature factor;} \]
\[ \text{De} = \frac{Re}{d/D} \quad \text{Dean number;} \]
\[ \text{Gr}_q = g \beta_q \frac{d^4 \rho^2}{\lambda \mu^2} \quad \text{Grashof number defined by the heat flux specified on the surface;} \]
\[ \text{Gr}_A = g \beta A \left( \frac{dT_f}{dx} \right) \frac{1}{16v^2} \quad \text{Grashof number defined by the longitudinal gradient of the bulk temperature of the liquid;} \]
\[ \text{Gr}_A = \frac{\text{Gr}_q}{4 \text{RePr}} \]

\[ \text{Nu} = \frac{\alpha d_e}{\lambda} \quad \text{Nusselt number;} \]
\[ \text{Pr} = \frac{\mu c_p}{\lambda} \quad \text{Prandtl number;} \]
\[ \text{Pr}_t = \frac{\varepsilon}{\varepsilon_q} \quad \text{turbulent Prandtl number;} \]
\[ \text{Re} = \frac{ud_e}{\nu} \quad \text{Reynolds number;} \]
\[ \text{St} = \frac{\text{Nu}}{\text{RePr}} \quad \text{Stanton number.} \]

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;
\[ (\bar{\cdot}) \] - averaging;
\[ (\cdot') \] - oscillating component.

The remaining symbols are defined in the text.