Appendix A

Nomenclature

\( A_i \) – internal heat transfer area (m²)
\( A_o \) – external heat transfer area (m²)
\( A_s \) – cross flow area of shell side (m²)
\( A_t \) – cross sectional area of tube side (m²)
\( B_s \) – baffle spacing (m)

\( C_{p_{ws}}, C_{p_{wt}} \) – specific heat of cold water in shell side and tube side (J/kg K)

\( C_{p_{fs}}, C_{p_{ft}} \) – specific heat of pure liquid in shell side and tube side (J/kg K)

\( C_{p_{ts}}, C_{p_{tt}} \) – specific heat of process stream in shell and tube side (J/kg K)

\( C_{p_{hs}}, C_{p_{ht}} \) – specific heat of hot water in shell and tube side (J/kg K)

\( D_i \) – inner diameter of the tube (m)
\( D_o \) – outer diameter of the tube (m)
\( D_s \) – inner diameter of shell (m)
\( D_e \) – equivalent diameter (m)

\( E \) – thermal effectiveness of process stream/pure liquid

\( F \) – heat capacity ratio

\( h_i, h_o \) - inside and outside heat transfer coefficients (W/m²K)

\( h_{1s} \) - heat transfer coefficient of pure liquid/pure water in shell side (W/m²K)

\( h_{1t} \) - heat transfer coefficient of pure liquid/pure water in tube side (W/m²K)

\( h_{2s} \) - two-phase heat transfer coefficient in shell side (W/m²K)

\( h_{2t} \) - two-phase heat transfer coefficient in tube side (W/m²K)
$k_{ws}, k_{wt}$ – thermal conductivity of cold water in shell side and tube side (W/mK)

$k_{hs}, k_{ht}$ – thermal conductivity of pure liquid in shell side and tube side (W/mK)

$k_{ts}, k_{tt}$ – thermal conductivity of process stream in shell and tube side (W/mK)

$L$ – length of tube (m)

$m$ – mass flow rate of process stream (kg/s)

$m_{hs}$ – mass flow rate of hot water in shell side (kg/s)

$m_{ht}$ – mass flow rate of hot water in tube side (kg/s)

$m_{ht}, m_{fs}$ – mass flow rate of single-phase fluid in tube side and shell side (kg/s)

$m_{wt}, m_{ws}$ – mass flow rate of cold water in tube side and shell side (kg/s)

$m_{ht}, m_{fs}$ – mass flow rate of two-phase fluid in tube side and shell side (kg/s)

$N_t$ – number of tubes

$N_P$ - number of passes

$P_t$ – tube pitch (m)

$Q_{hs}, Q_{ht}$ – heat flow rate of hot water in shell and tube side (W)

$Q_{ss}, Q_{st}$ – heat flow rate of single phase fluid in shell and tube side (W)

$Q_{st}, Q_{tt}$ – heat flow rate of process stream in shell and tube side (W)

$T_{h1}$- inlet temperature of hot water in tube side (K)

$T_{h2}$- outlet temperature of hot water in tube side (K)

$T_{c1}$- inlet temperature of cold fluid in shell side (K)

$T_{c2}$- outlet temperature of cold fluid in shell side (K)

$T_{w1}$ & $T_{w2}$- wall temperatures (K)

$T_{hi}$ - inlet temperature of hot water (K)

$T_{ho}$ - outlet temperature of hot water (K)
\( T_{ci} \) - inlet temperature of cold fluid (K)
\( T_{co} \) - outlet temperature of cold fluid (K)
\( U \) - overall heat transfer coefficient (W/m\(^2\)K)
\( u_s/u_t \) – ratio of shell side velocity to tube side velocity
\( u_{ss}, u_{tt} \) – velocity of process stream in shell side and tube side (m/s)
\( V_{fs}, V_{ft} \) – volumetric flow rate of pure liquid in shell side and tube side (m\(^3\)/s)
\( V_{fs}, V_{ft} \) – volumetric flow rate of two-phase fluid in shell side and tube side (m\(^3\)/s)
\( V_{hs}, V_{ht} \) – volumetric flow rate of hot water in shell and tube side (m\(^3\)/s)
\( V_{ws}, V_{wt} \) – volumetric flow rate of cold water in shell and tube side (m\(^3\)/s)

**Greek letters**

\( \Delta T \) - temperature difference in process side (K)
\( \Delta T_{ln} \) - logarithmic mean temperature (K)
\( \mu_{ws}, \mu_{wt} \) – density of cold water in shell side and tube side (kg/ms)
\( \mu_{fs}, \mu_{ft} \) – density of pure liquid in shell side and tube side (kg/ms)
\( \mu_{ts}, \mu_{tt} \) – density of process stream in shell and tube side (kg/ms)
\( \rho_{ws}, \rho_{wt} \) – density of cold water in shell side and tube side (kg/m\(^3\))
\( \rho_{fs}, \rho_{ft} \) – density of pure liquid in shell side and tube side (kg/m\(^3\))
\( \rho_{ts}, \rho_{tt} \) – density of process stream in shell and tube side (kg/m\(^3\))
\( \rho_{hs}, \rho_{ht} \) – density of hot water in shell side and tube side (kg/m\(^3\))
\( \Phi_{Lt}, \Phi_{Ls} \) – Modified two-phase multiplier for tube side and shell side
\( \chi^2_{tt}, \chi^2_{ts} \) – L-M parameter for tube side and shell side