Determination of the maximum skin temperature of a reformer tube as per API 530

Required Parameters:

Reformer Radiant Box Parameters:

Design Temperature of Tubes	$T_{des} := 1675\,°F$
Average Operating Pressure of Tubes	$P := 575 \cdot psi = 39.645 \cdot bar$
Centre-to-Centre Distance Between Tubes	$TS := 203.2 \cdot mm$
Outer Tube Diameter	$D_o := 132.08 \cdot mm$
Inner Tube Diameter	$D_i := 107.2 \cdot mm$
Number of tubes	$N := 280$
Thermal Conductivty of tube metal	$\lambda_{tm} := 42.2 \cdot \frac{W}{m \cdot K}$
Average radiant heat flux density for outside surface	$q_{Rave} := 12500 \cdot \frac{W}{m^2}$
Thickness of coke	$\delta_{coke} := 0 \cdot mm$
Thickness of tube	$\delta_{tav} := 12.5 \cdot mm$
Thermal conductivity of coke/scale	$\lambda_{coke} := 10 \cdot \frac{W}{m \cdot K}$
Length of reformer tube	$L := 42 \cdot ft = 12.802\,m$

Reformed Gas Process Parameters:

Temperature of vapor leaving reformer	$T := 800\,°C$
Flow rate of steam+feed gas (total)	$m_{tot} := 3.841 \cdot 10^5 \cdot \frac{lb}{hr} = 48.396\,\frac{kg}{s}$
Absolute viscosity of vapor at bulk temp	$\mu := 0.0186 \cdot Pa \cdot s$
Thermal conductivity of vapor	$\lambda := 0.1805 \cdot \frac{W}{m \cdot K}$
Specific heat capacity of vapor	$c := 2283 \cdot 10^3 \cdot \frac{J}{kg \cdot K}$

Calculations:

Mass flow per tube is given by:

$$m := \frac{m_{tot}}{N} = 0.173\,\frac{kg}{s}$$

Flow area within tube is given by:

$$A_i := \frac{\pi}{4}\cdot D_i^{\,2} = 9.026\times 10^{-3}\,m^2$$

$$q_{mA} := \frac{m}{A_i} = 19.15\,\frac{kg}{m^2\cdot s}$$

Areic flow is then calculated:

Reynold's Number:

$$Re := \frac{D_i\cdot q_{mA}}{\mu} = 110.37$$

Prandtl's Number:

$$Pr := \frac{c\cdot\mu}{\lambda} = 2.353\times 10^5$$

Heat Transfer Coefficient Adjustment Factor: $C_1 := 1.2$

Heat transfer cofficient of gas can now be calculated as follows

$$K := \frac{\lambda}{D_i}\cdot\left[3.65 + \frac{0.0668\cdot Re\cdot Pr\cdot\frac{D_i}{L}}{1 + 0.04\cdot\left(Re\cdot Pr\cdot\frac{D_i}{L}\right)^{\frac{2}{3}}}\right]\cdot C_1^{\,0.14} = 178.571\cdot\frac{W}{m^2\cdot K}$$

Factor accounting for longitudinal heat-flux density variations $F_L := 1.05$

Factor accounting for effect of tube metal temp. on radiant heat flux density $F_T := 1$

Factor accounting for circumferential heat flux density based on TS/D_o $F_{circ} := 1.28$

Convective heat flux around tubes $q_{conv} := 0 \cdot \frac{W}{m^2}$

Based on the above factors, the maximum heat flux density at any point within a row of tubes can be estimated as follows:

$$q_{Rmax} := F_{circ} \cdot F_L \cdot F_T \cdot q_{Rave} + q_{conv} = 1.68 \times 10^4 \cdot \frac{W}{m^2}$$

Tempterature difference across the fluid film ΔT_{ff}

$$\Delta T_{ff} := \frac{q_{Rmax}}{K} \cdot \left(\frac{D_o}{D_i - 2 \cdot \delta_{coke}} \right) = 115.915 \cdot K$$

Tempterature difference across coke/scale ΔT_{coke}

$$\Delta T_{coke} := \frac{q_{Rmax} \cdot \delta_{coke}}{\lambda_{coke}} \cdot \left(\frac{D_o}{D_i - \delta_{coke}} \right) = 0$$

Tempterature difference across tube wall ΔT_{tw}

$$\Delta T_{tw} := \frac{q_{Rmax} \cdot \delta_{tav}}{\lambda_{tm}} \left(\frac{D_o}{D_o - \delta_{tav}} \right) = 5.496 \cdot K$$

Maximum tube metal temperature T_{max}

$$T_{max} := T + \Delta T_{ff} + \Delta T_{coke} + \Delta T_{tw} = 1194.562\,K$$

$$T_{max} = 1690.541 \cdot {}^\circ F$$