Spiral-tube Heat Exchange in COMSOL

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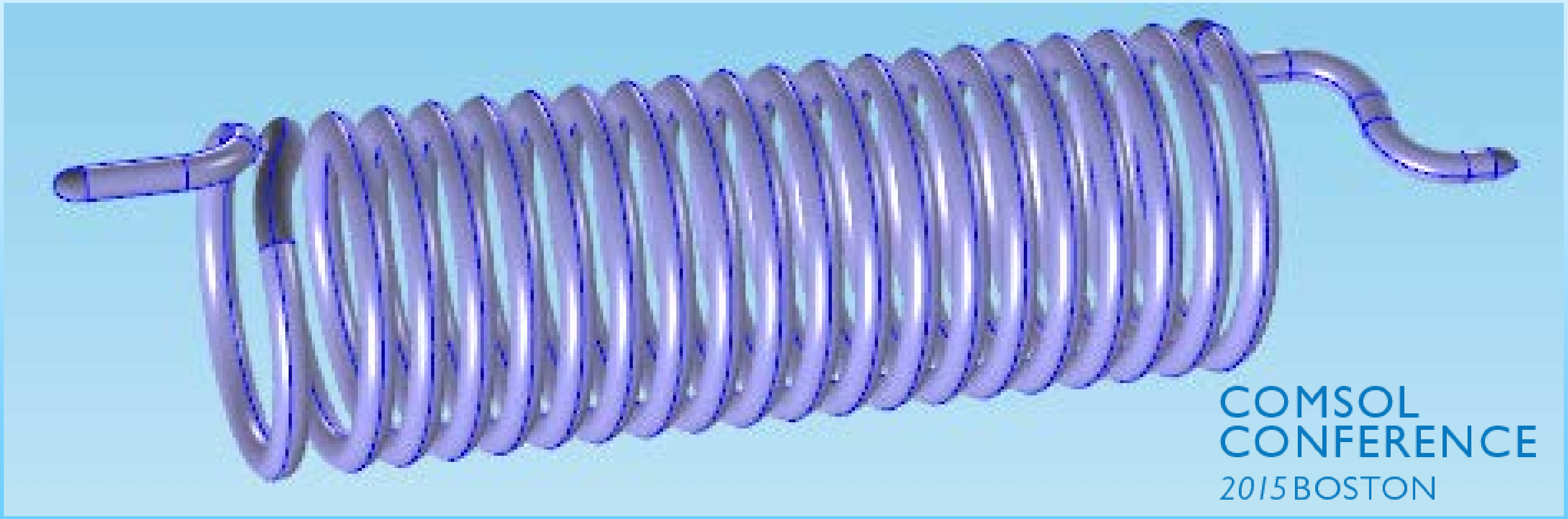
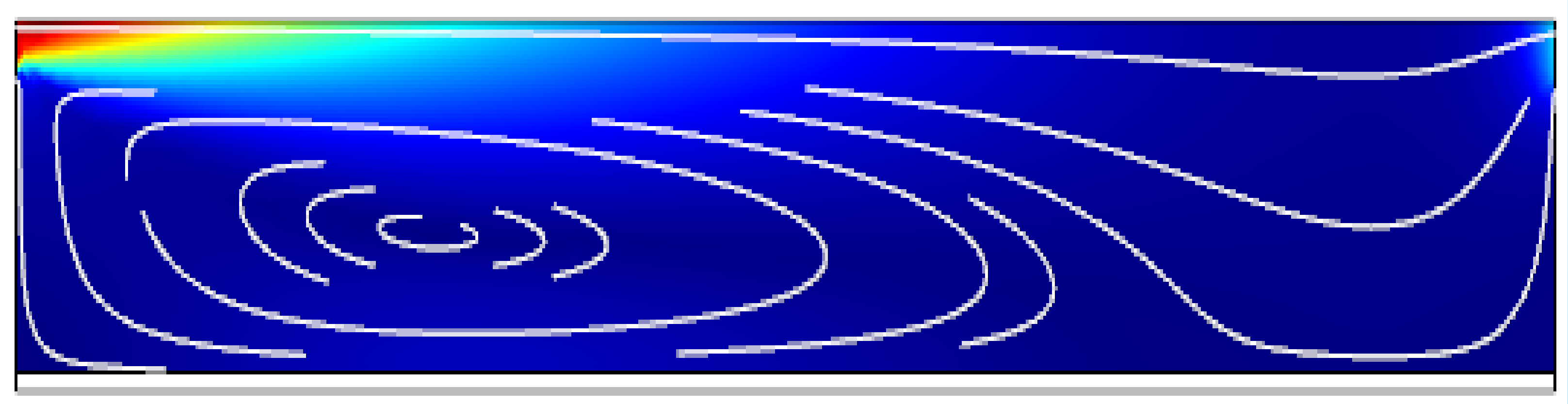


CLOSE-WOUND METAL COIL

Axis-symmetric Core Convection Model

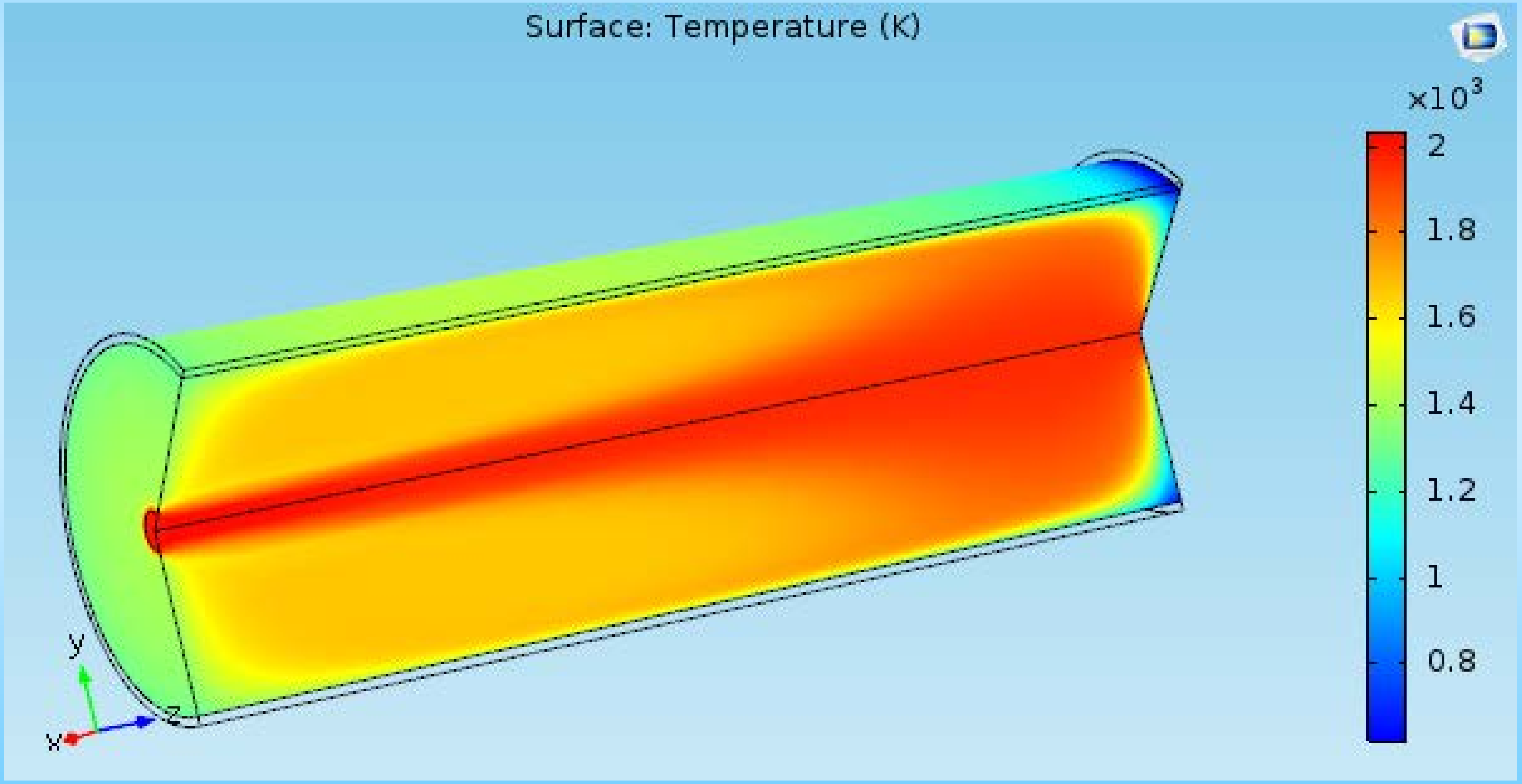
4” entrance turbulent jet

exit at an 8” orifice

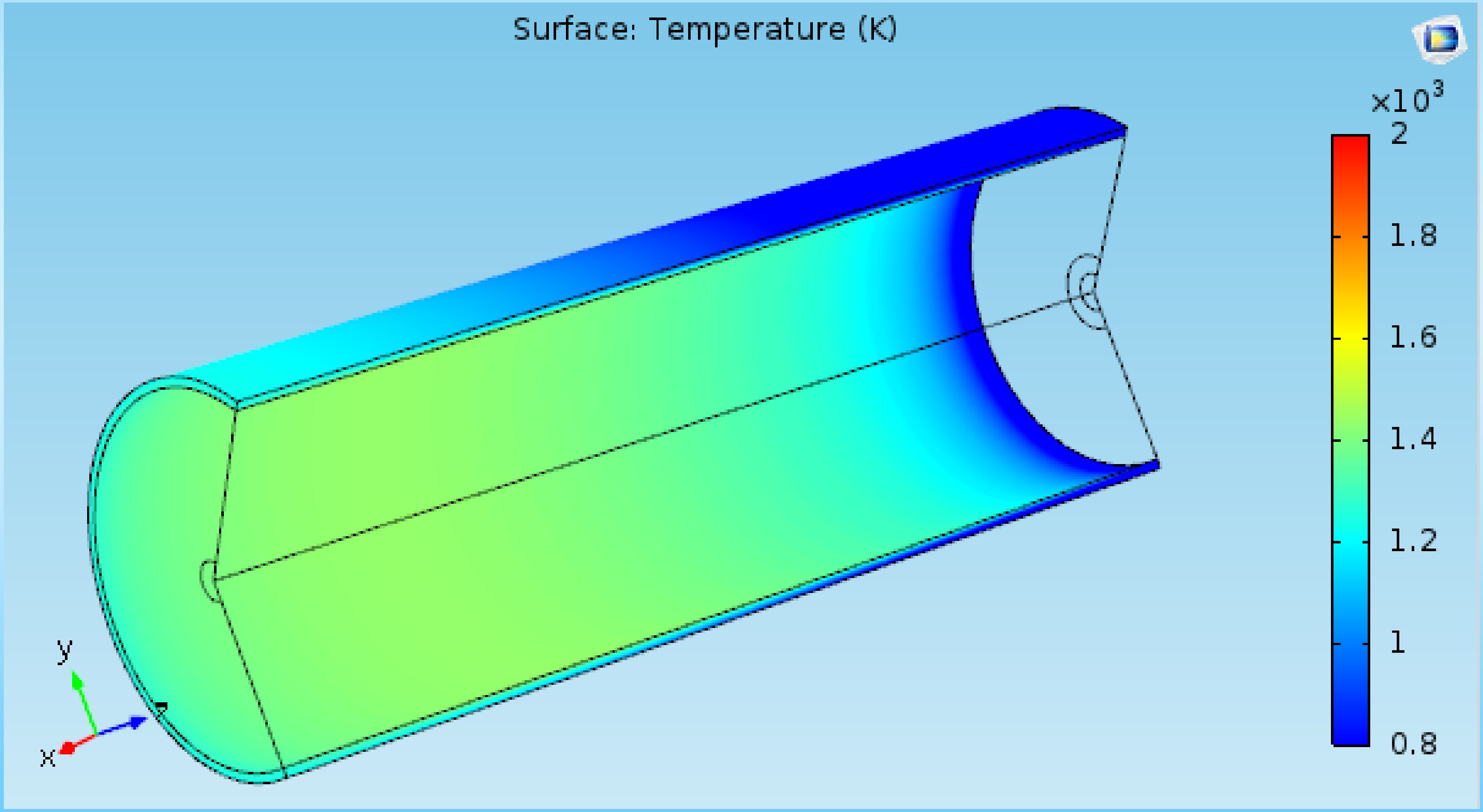


solid conduction edge-region

Core Temperatures



Edge-Region Temperatures



Spiral Tube ID Model

distance along the coil, *s*

$$-A_f \frac{dp_f}{ds} = \tau_w P_f \qquad \text{or} \qquad \frac{dp_f}{ds} = -4\tau_w / D_H$$

$$\tau_w = (\tfrac{1}{2})\rho_f U_f^2 C_f \qquad C_f = r_{cs} 0.046 / Re_f^{0.2}$$

$$r_{cs} = 1 + 0.11 Re_f^{0.23} (D_H/D_C)^{0.14} \approx 2.0$$

heat balance yields

$$\frac{d(\dot{m} C_p T)_f}{ds} = q_w P_f \qquad \text{or} \qquad \dot{m} C_p \frac{dT_f}{ds} = q_w \pi D_H$$

wall heat flux $\quad q_w = h_f (T_w - T_f)$

heat transfer coefficient is given by Reynold’s analogy

$$h_f / (\rho C_p U)_f \equiv St \approx \frac{C_f}{2} Pr^{-2/3}$$

Axial Tube ID Integration

s = (πD_C/P)x ; therefore d/ds = P/(πD_C)d/dx

$$\frac{P}{\pi D_C}\frac{dp_f}{dx} = -4\tau_w/D_H$$

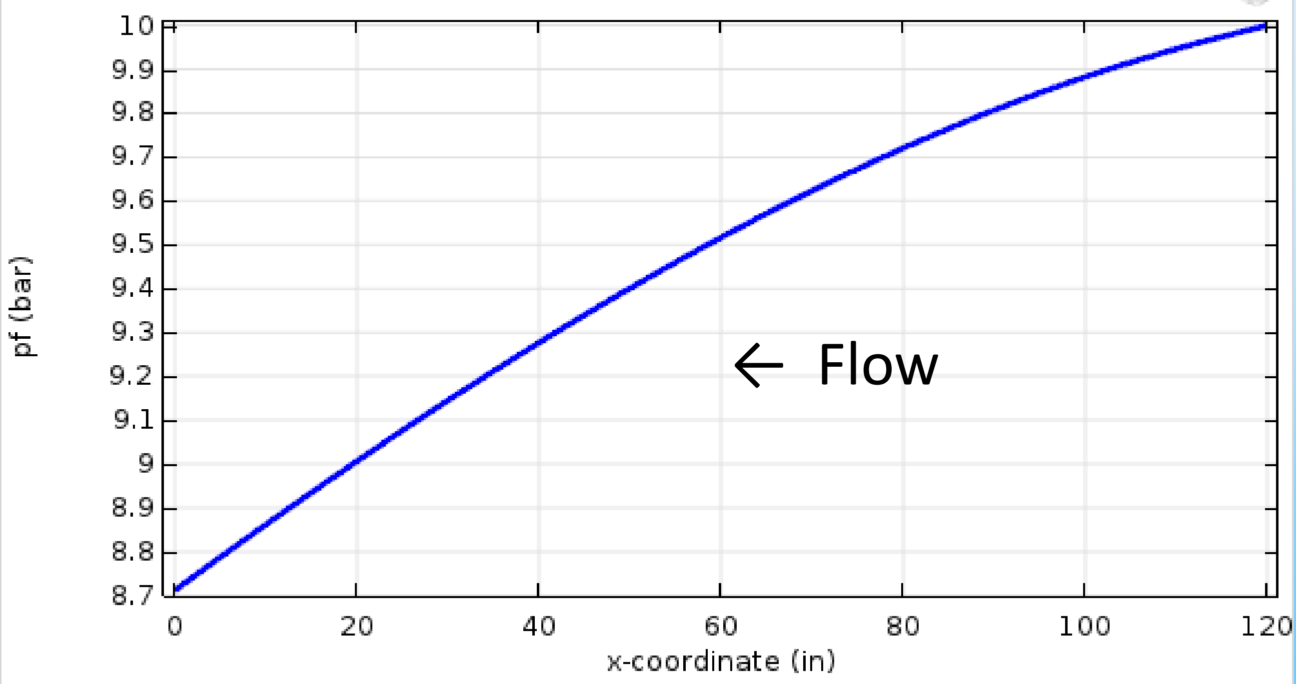
$$\dot{m}C_p\frac{P}{\pi D_C}\frac{dT_f}{dx} = q_w\pi D_H$$

$S_f = p_f/p_{fin}$

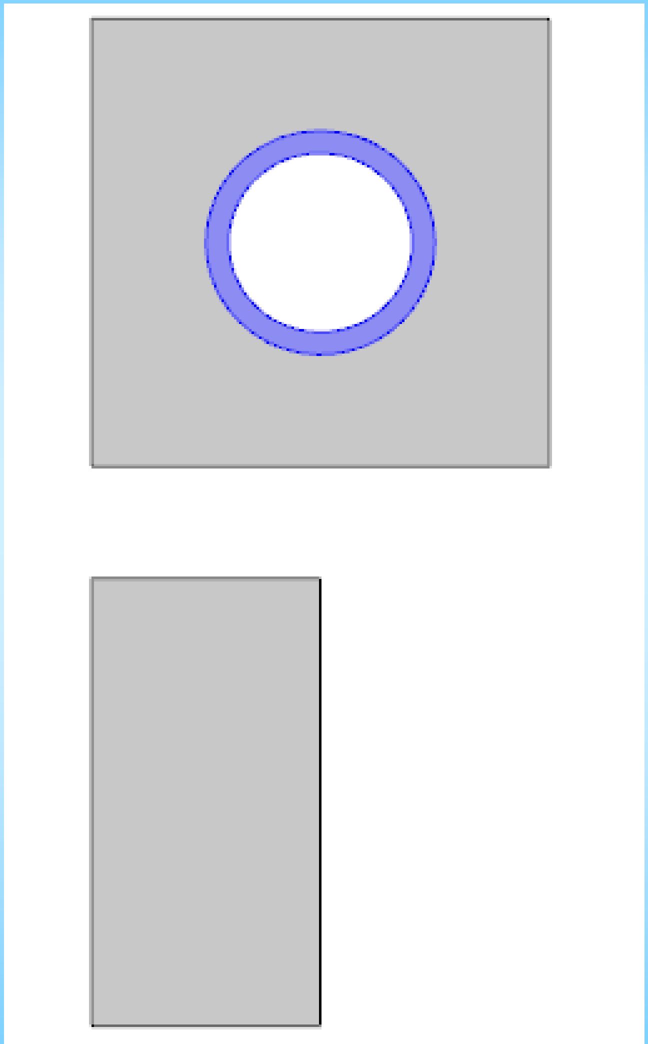
$R_f = T_f/T_{fin}$

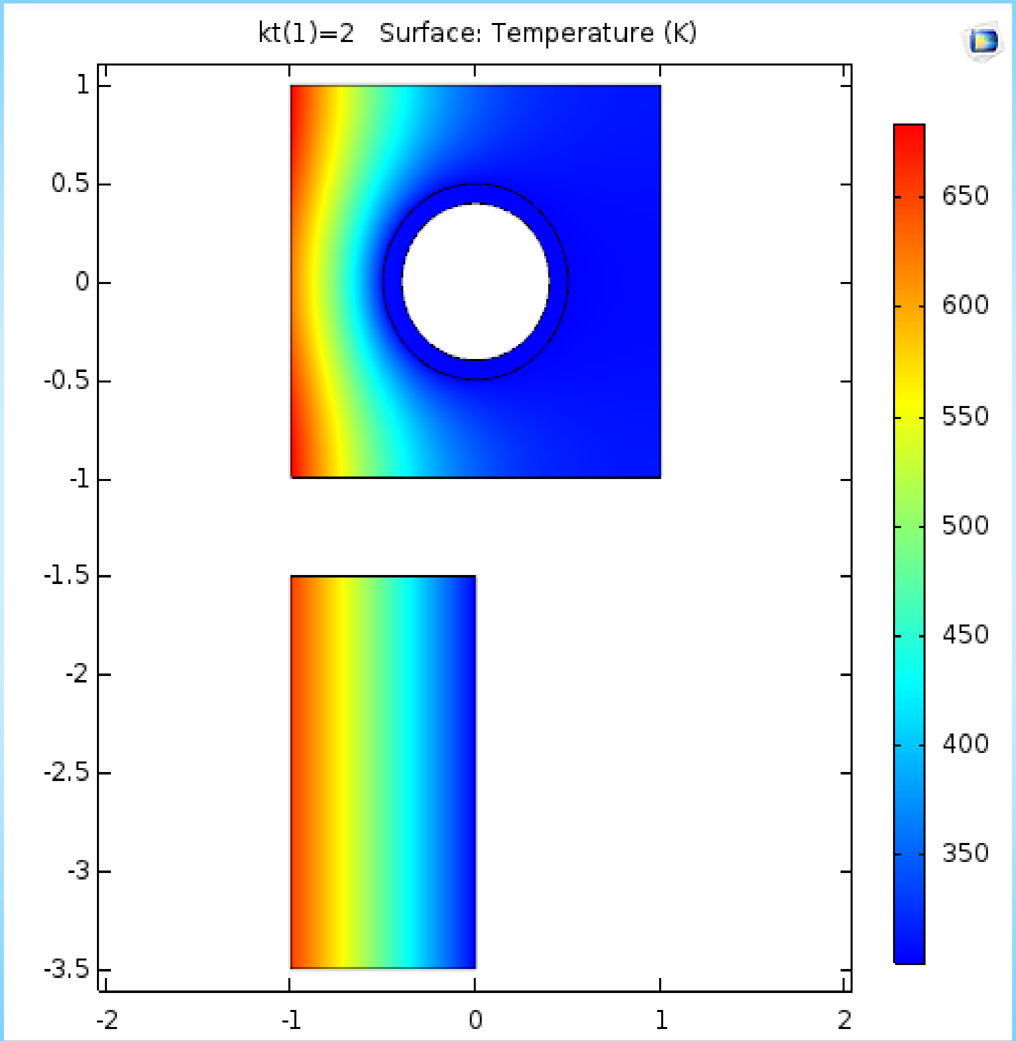
$$P\frac{dS_f}{dx} = -4\pi\left(\tau_w/p_{fin}\right)D_C/D_H$$

$$P\frac{dR_f}{dx} = \pi^2 q_w D_C D_H/\dot{m}C_p T_{fin}$$

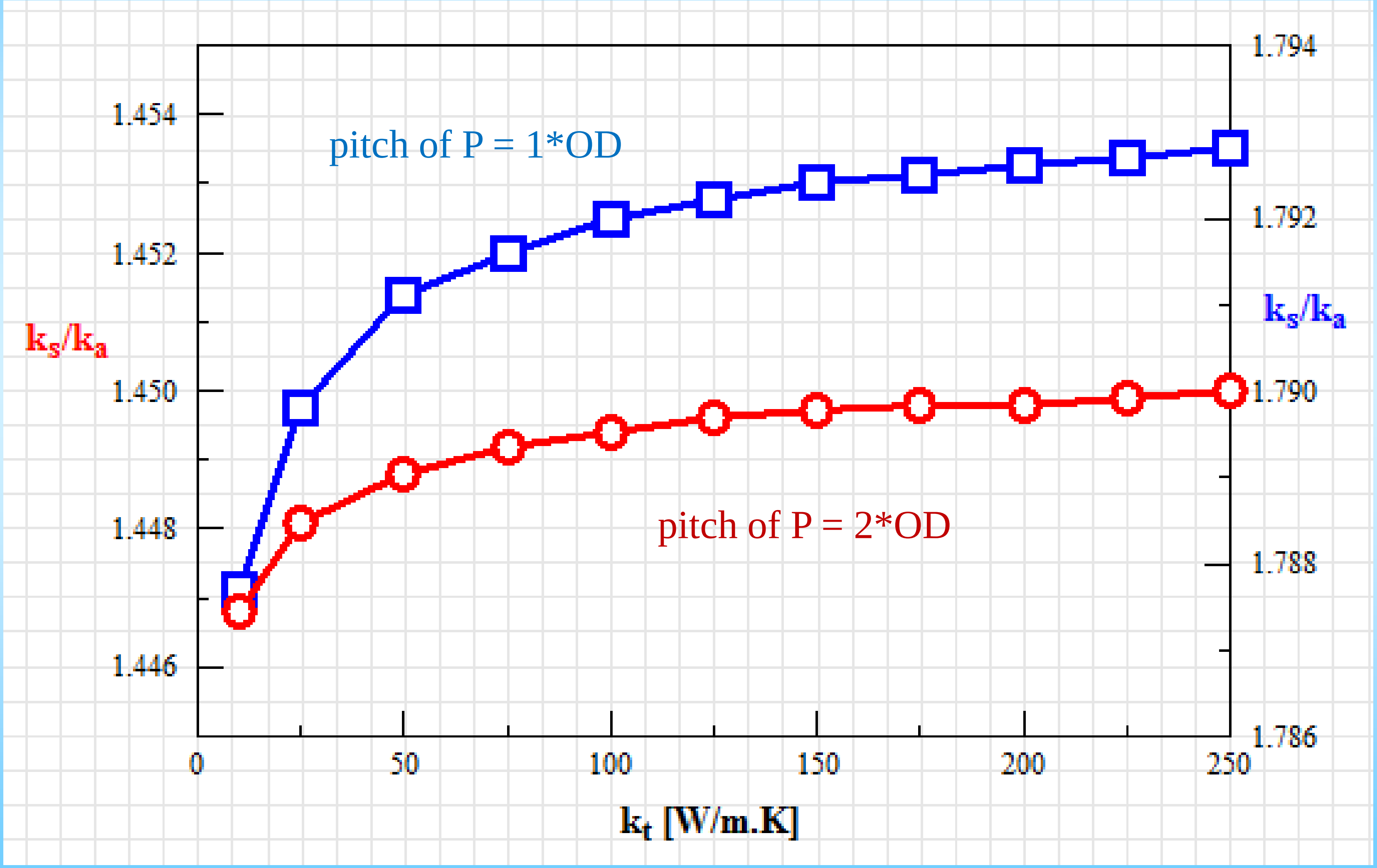


Shape Factor

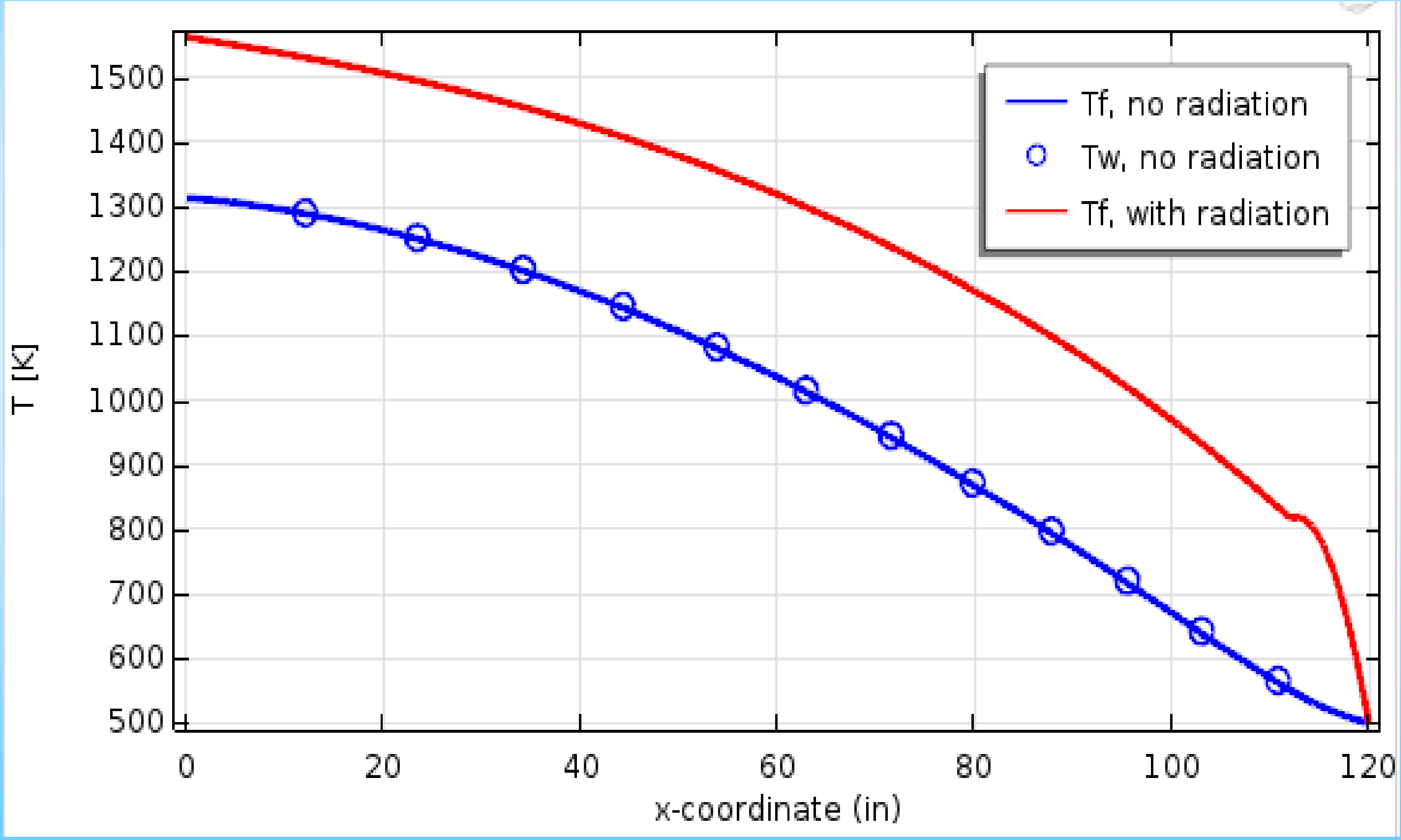




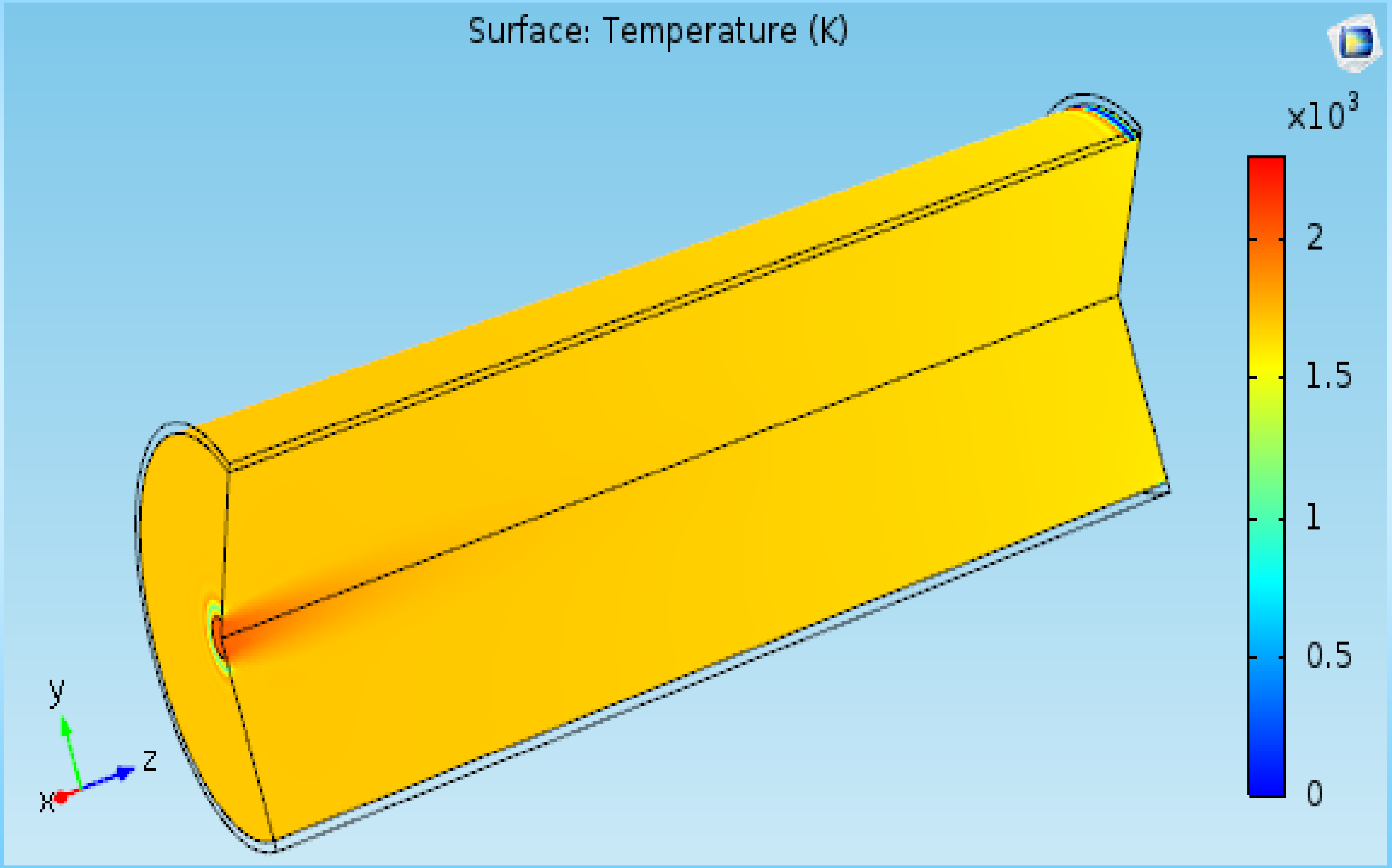
Determine effective conductivity, k_s so the left-most temperatures are equal.


pitch of P = 1*OD
pitch of P = 2*OD
k_s/k_a
k_s/k_a
1.454
1.452
1.450
1.448
1.446
1.794
1.792
1.790
1.788
1.786
0
50
100
150
200
250
k_t [W/m.K]

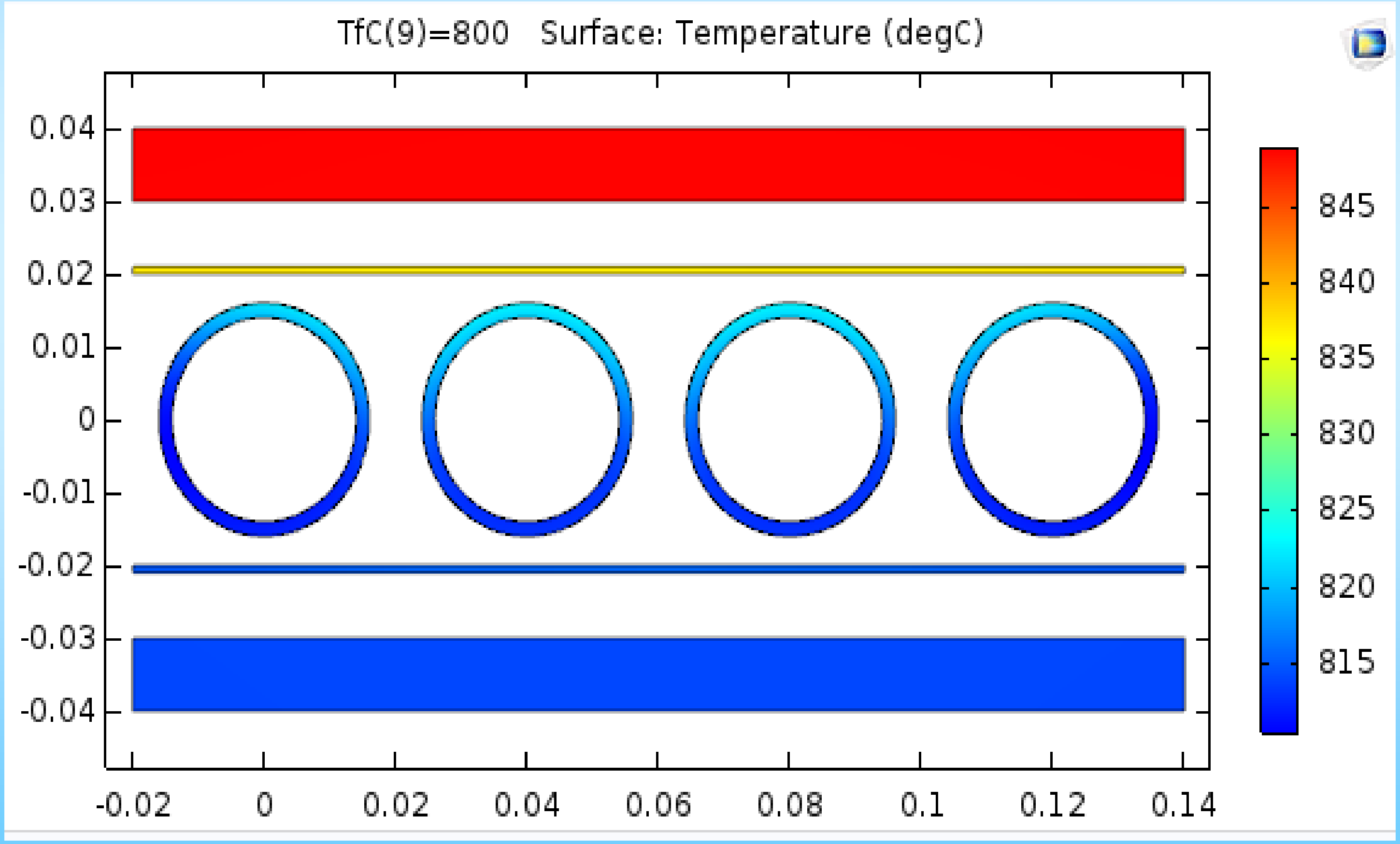
Tube Wall and Fluid Temperatures



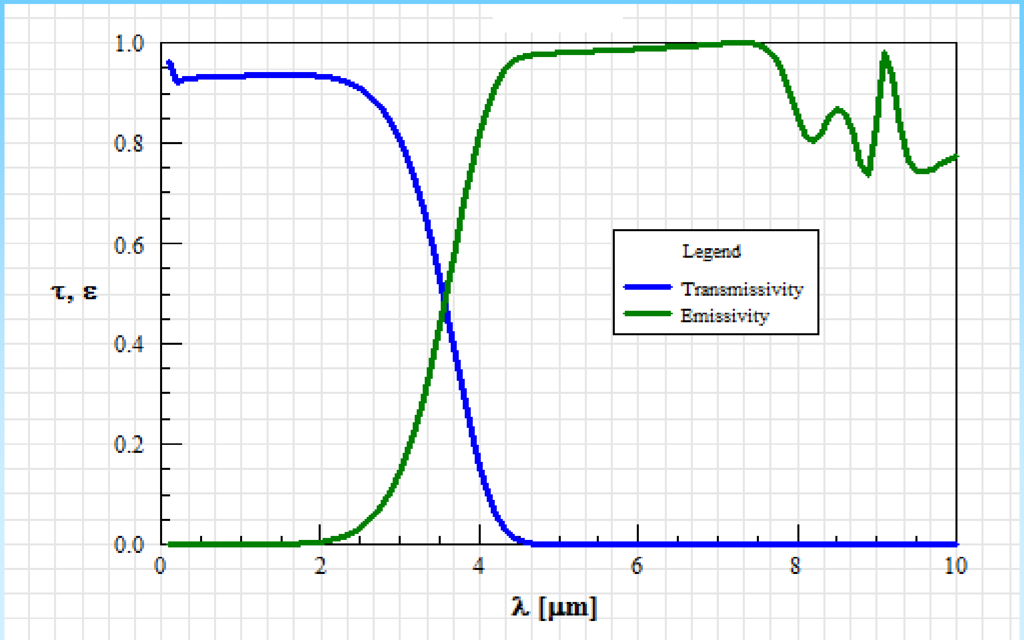
Core Temperatures with Medium Radiation

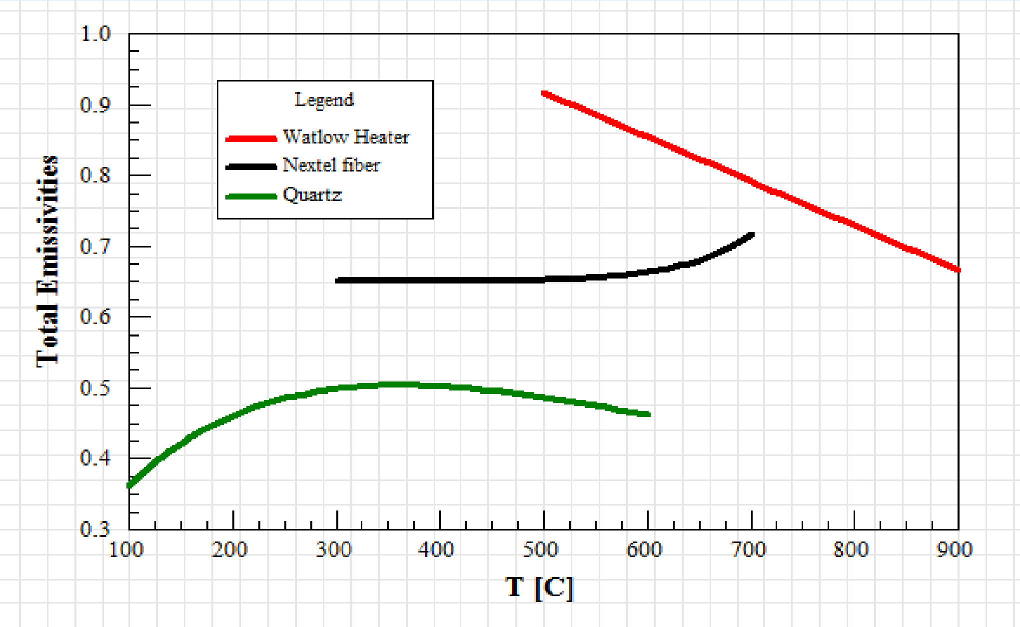


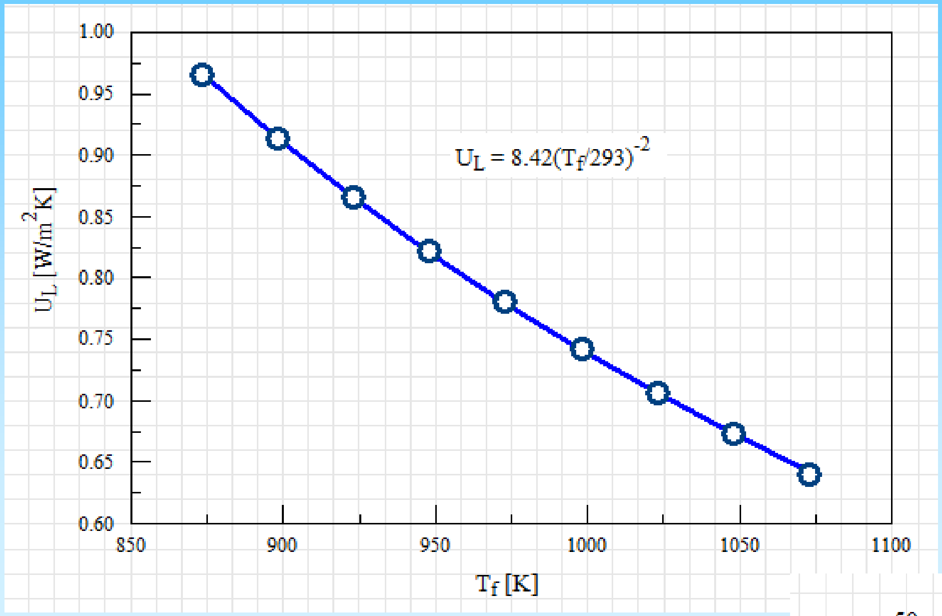
OPEN-WOUND QUARTZ COIL



Radiation Properties

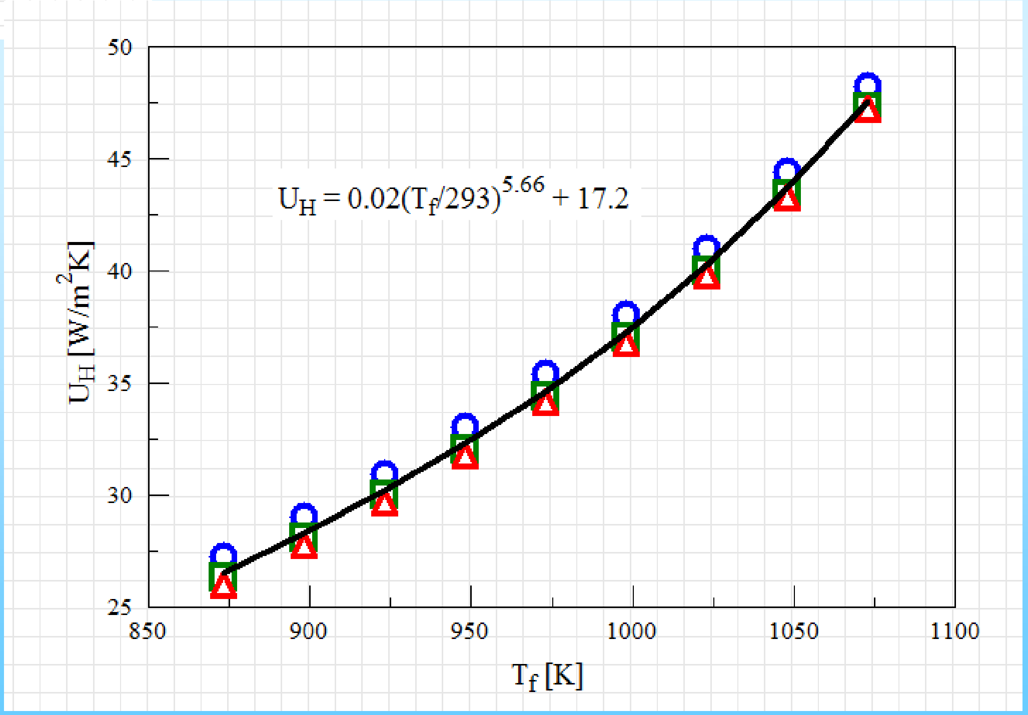




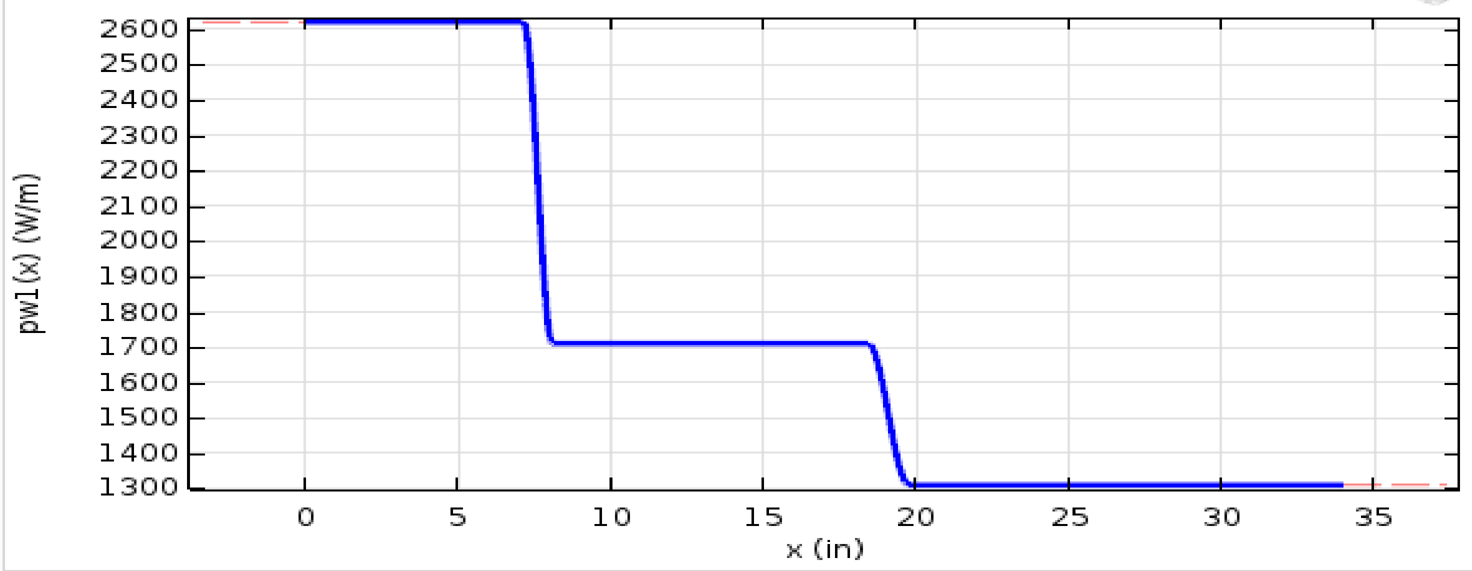


heat loss coefficient

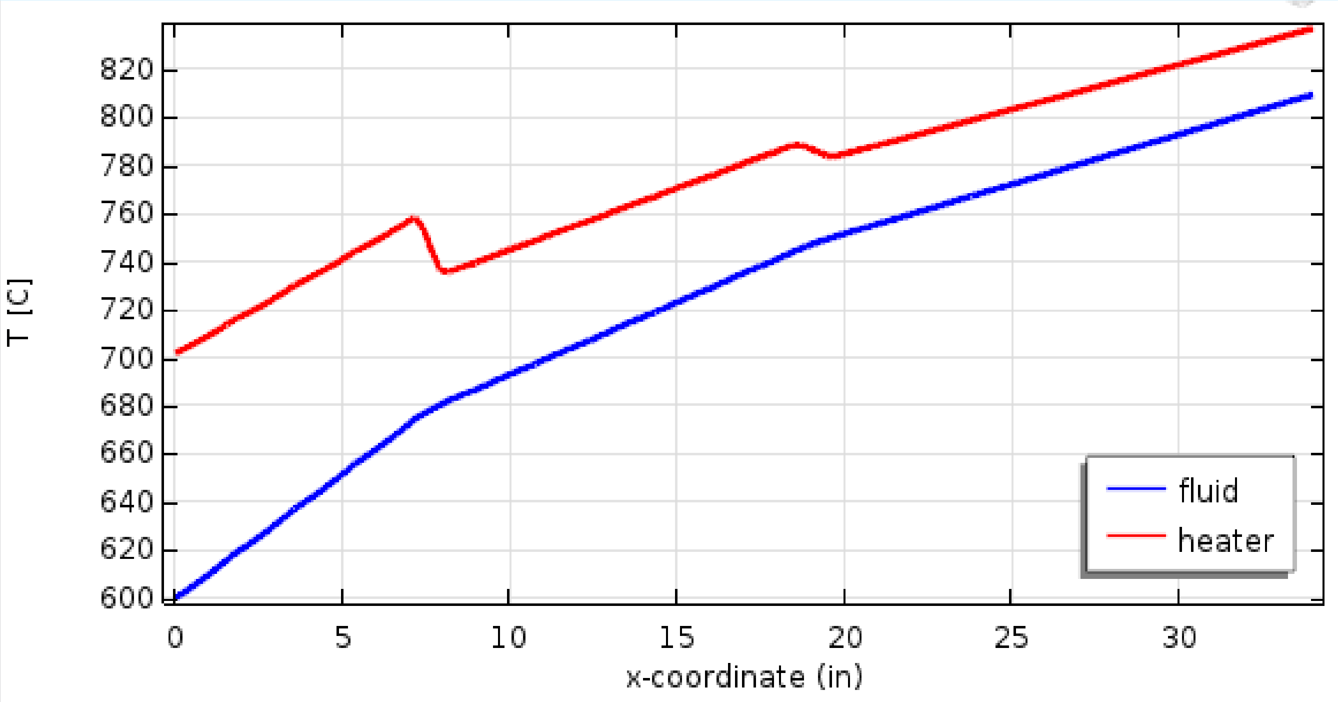
heater temperature coefficient



heater power



Fluid & heater temperatures



CONCLUSION

- *Coil Heat Exchangers* with different length scales and processes were modeled with COMSOL; shape factors linked processes into a unified model.

- *Combustion Example*: core turbulent convection and radiation heat transfer were linked to the spiral flow.

- *Electric-heater Example*: complex radiation to bank of tubes was simplified to an overall heat transfer coefficient.

Thank you