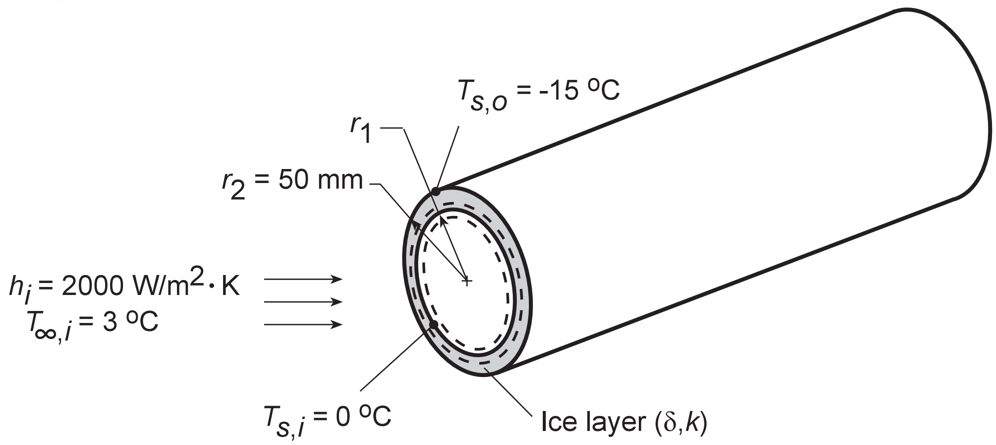
PROBLEM 3.60

KNOWN: Pipe wall temperature and convection conditions associated with water flow through the pipe and ice layer formation on the inner surface.

FIND: Ice layer thickness δ.

SCHEMATIC:



ASSUMPTIONS: (1) One-dimensional, steady-state conduction, (2) Negligible pipe wall thermal resistance, (3) negligible ice/wall contact resistance, (4) Constant k.

PROPERTIES: *Table A.3,* Ice (T = 265 K): k ≈ 1.94 W/m·K.

ANALYSIS: Performing an energy balance for a control surface about the ice/water interface, it follows that, for a unit length of pipe,

$$q'_{conv} = q'_{cond}$$

$$h_i\left(2\pi r_1\right)\left(T_{\infty,i} - T_{s,i}\right) = \frac{T_{s,i} - T_{s,o}}{\ln\left(r_2/r_1\right)/2\pi k}$$

Dividing both sides of the equation by r_2,

$$\frac{\ln\left(r_2/r_1\right)}{\left(r_2/r_1\right)} = \frac{k}{h_i r_2} \times \frac{T_{s,i} - T_{s,o}}{T_{\infty,i} - T_{s,i}} = \frac{1.94\,\mathrm{W/m\cdot K}}{\left(2000\,\mathrm{W/m^2\cdot K}\right)\left(0.05\,\mathrm{m}\right)} \times \frac{15^\circ\mathrm{C}}{3^\circ\mathrm{C}} = 0.097$$

The equation is satisfied by $r_2/r_1 = 1.114$, in which case $r_1 = 0.050$ m/1.114 = 0.045 m, and the ice layer thickness is

$$\delta = r_2 - r_1 = 0.005\,\mathrm{m} = 5\,\mathrm{mm}$$ <

COMMENTS: With no flow, $h_i \to 0$, in which case $r_1 \to 0$ and complete blockage could occur. The pipe should be insulated.