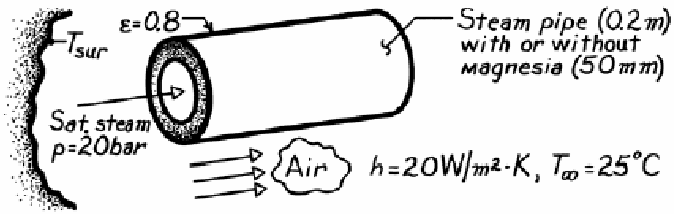
PROBLEM 3.48

KNOWN: Saturated steam conditions in a pipe with prescribed surroundings.

FIND: (a) Heat loss per unit length from bare pipe and from insulated pipe, (b) Pay back period for insulation.

SCHEMATIC:

Steam Costs:
$4 for 10^9 J
Insulation Cost:
$100 per meter
Operation time:
7500 h/yr



ASSUMPTIONS: (1) Steady-state conditions, (2) One-dimensional heat transfer, (3) Constant properties, (4) Negligible pipe wall resistance, (5) Negligible steam side convection resistance (pipe inner surface temperature is equal to steam temperature), (6) Negligible contact resistance, (7) $T_{sur} = T_\infty$.

PROPERTIES: *Table A-6*, Saturated water (p = 20 bar): $T_{sat} = T_s = 486K$; *Table A-3*, Magnesia, 85% ($T \approx 392K$): k = 0.058 W/m·K.

ANALYSIS: (a) Without the insulation, the heat loss may be expressed in terms of radiation and convection rates,

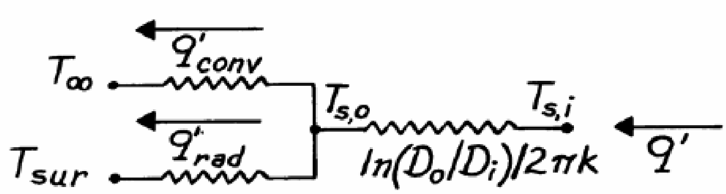
$$q' = \varepsilon\pi D\sigma\left(T_s^4 - T_{sur}^4\right) + h(\pi D)(T_s - T_\infty)$$

$$q' = 0.8\pi(0.2m)5.67\times10^{-8}\ \frac{W}{m^2\cdot K^4}\left(486^4 - 298^4\right)K^4$$

$$+20\frac{W}{m^2\cdot K}(\pi\times0.2m)\ (486\text{-}298)K$$

$$q' = (1365+2362)\,W/m = 3727\ W/m.$$ <

With the insulation, the thermal circuit is of the form



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From an energy balance at the outer surface of the insulation,

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

$$\frac{T_{s,i} - T_{s,o}}{\ln(D_o / D_i)/2\pi k} = h\pi D_o (T_{s,o} - T_\infty) + \varepsilon\sigma\pi D_o (T_{s,o}^4 - T_{sur}^4)$$

$$\frac{(486 - T_{s,o})K}{\dfrac{\ln(0.3m/0.2m)}{2\pi(0.058\ W/m\cdot K)}} = 20\frac{W}{m^2\cdot K}\pi(0.3m)(T_{s,o} - 298K)$$

$$+0.8 \times 5.67 \times 10^{-8}\frac{W}{m^2\cdot K^4}\pi(0.3m)(T_{s,o}^4 - 298^4)K^4.$$

By trial and error, we obtain

$$T_{s,o} \approx 305K$$

in which case

$$q' = \frac{(486\text{-}305)K}{\dfrac{\ln(0.3m/0.2m)}{2\pi(0.055\ W/m\cdot K)}} = 163\ W/m. \qquad <$$

(b) The yearly energy savings per unit length of pipe due to use of the insulation is

$$\frac{\text{Savings}}{\text{Yr}\cdot\text{m}} = \frac{\text{Energy Savings}}{\text{Yr.}} \times \frac{\text{Cost}}{\text{Energy}}$$

$$\frac{\text{Savings}}{\text{Yr}\cdot\text{m}} = (3727 - 163)\frac{J}{s\cdot m} \times 3600\frac{s}{h} \times 7500\frac{h}{Yr} \times \frac{\$4}{10^9 J}$$

$$\frac{\text{Savings}}{\text{Yr}\cdot\text{m}} = \$385/\text{Yr}\cdot\text{m}.$$

The pay back period is then

$$\text{Pay Back Period} = \frac{\text{Insulation Costs}}{\text{Savings/Yr.}\cdot\text{m}} = \frac{\$100/\text{m}}{\$385/\text{Yr}\cdot\text{m}}$$

$$\text{Pay Back Period} = 0.26\ \text{Yr} = 3.1\ \text{mo.} \qquad <$$

COMMENTS: Such a low pay back period is more than sufficient to justify investing in the insulation.