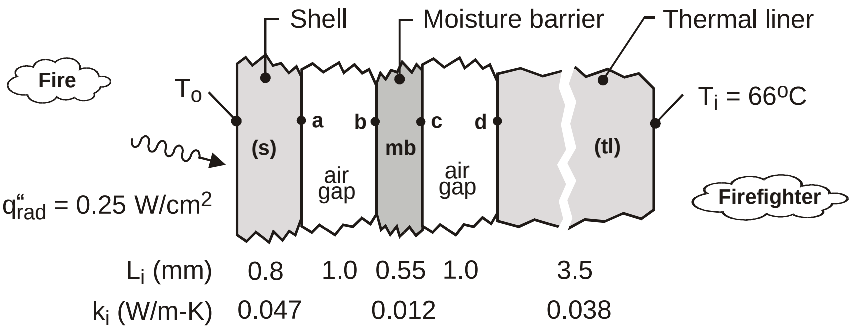
PROBLEM 3.24

KNOWN: Representative dimensions and thermal conductivities for the layers of fire-fighter's protective clothing, a turnout coat.

FIND: (a) Thermal circuit representing the turnout coat; tabulate thermal resistances of the layers and processes; and (b) For a prescribed radiant heat flux on the fire-side surface and temperature of T_i = 60°C at the inner surface, calculate the fire-side surface temperature, T_o.

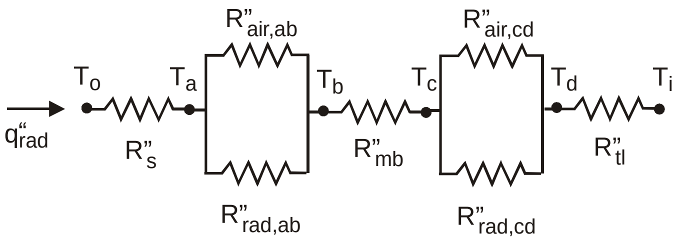
SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) One-dimensional conduction through the layers, (3) Heat is transferred by conduction and radiation exchange across the stagnant air gaps, (3) Constant properties.

PROPERTIES: *Table A-4*, Air (470 K, 1 atm): $k_{ab} = k_{cd}$ = 0.0387 W/m·K.

ANALYSIS: (a) The thermal circuit is shown with labels for the temperatures and thermal resistances.



The conduction thermal resistances have the form $R''_{cd} = L/k$ while the radiation thermal resistances across the air gaps have the form

$$R''_{rad} = \frac{1}{h_{rad}} = \frac{1}{4\sigma T_{avg}^3}$$

The linearized radiation coefficient follows from Eqs. 1.8 and 1.9 with ε = 1 where T_{avg} represents the average temperature of the surfaces comprising the gap

$$h_{rad} = \sigma\left(T_1 + T_2\right)\left(T_1^2 + T_2^2\right) \approx 4\sigma T_{avg}^3$$

For the radiation thermal resistances tabulated below, we used T_{avg} = 470 K.

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PROBLEM 3.24 (Cont.)

	Shell (s)	Air gap (a-b)	Barrier (mb)	Air gap (c-d)	Liner (tl)	*Total* (tot)
$R''_{cd}\left(m^2 \cdot K/W\right)$	0.01702	0.0222	0.04583	0.0222	0.0921	--
$R''_{rad}\left(m^2 \cdot K/W\right)$	--	0.04246	--	0.04246	--	--
$R''_{gap}\left(m^2 \cdot K/W\right)$	--	0.0146	--	0.0146	--	--
R''_{total}	--	--	--	--	--	0.1842

From the thermal circuit, the resistance across the gap for the conduction and radiation processes is

$$\frac{1}{R''_{gap}} = \frac{1}{R''_{cd}} + \frac{1}{R''_{rad}}$$

and the total thermal resistance of the turn coat is

$$R''_{tot} = R''_{cd,s} + R''_{gap,a-b} + R''_{cd,mb} + R''_{gap,c-d} + R''_{cd,tl}$$

(b) If the heat flux through the coat is 0.25 W/cm^2, the fire-side surface temperature T_o can be calculated from the rate equation written in terms of the overall thermal resistance.

$$q'' = \left(T_o - T_i\right)/R''_{tot}$$

$$T_o = 66°C + 0.25\ W/cm^2 \times \left(10^2\,cm/m\right)^2 \times 0.1842\ m^2 \cdot K/W$$

$$T_o = 526°C$$ <

COMMENTS: (1) From the tabulated results, note that the thermal resistance of the moisture barrier (mb) is nearly 3 times larger than that for the shell or air gap layers. The thermal liner has the greatest thermal resistance. (2) The air gap conduction and radiation resistances were calculated based upon the average temperature of 570 K. This value was determined by setting $T_{avg} = (T_o + T_i)/2$ and solving the equation set using *IHT* with $k_{air} = k_{air}(T_{avg})$.