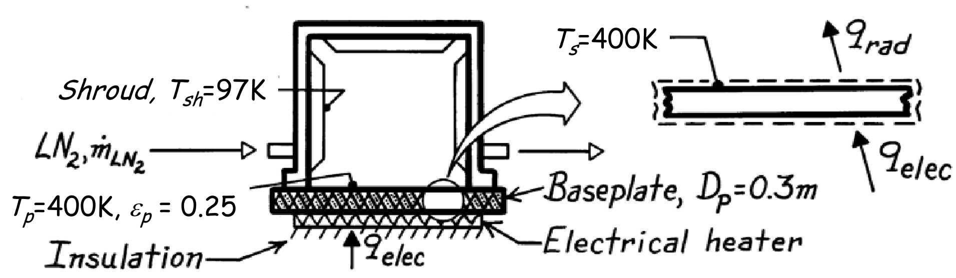
PROBLEM 1.34

KNOWN: Vacuum enclosure maintained at 97 K by liquid nitrogen shroud while baseplate is maintained at 400 K by an electrical heater.

FIND: (a) Electrical power required to maintain baseplate, (b) Liquid nitrogen consumption rate, (c) Effect on consumption rate if aluminum foil ($\varepsilon_p = 0.09$) is bonded to baseplate surface.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) No heat losses from backside of heater or sides of plate, (3) Vacuum enclosure large compared to baseplate, (4) Enclosure is evacuated with negligible convection, (5) Liquid nitrogen (LN_2) is heated only by heat transfer to the shroud, and (6) Foil is intimately bonded to baseplate.

PROPERTIES: Heat of vaporization of liquid nitrogen (given): 125 kJ/kg.

ANALYSIS: (a) From an energy balance on the baseplate,

$$\dot{E}_{in} - \dot{E}_{out} = 0 \qquad q_{elec} - q_{rad} = 0$$

and using Eq. 1.7 for radiative exchange between the baseplate and shroud,

$$q_{elec} = \varepsilon_p A_p \sigma \left(T_p^4 - T_{sh}^4\right).$$

Substituting numerical values, with $A_p = \left(\pi D_p^2/4\right)$, find

$$q_{elec} = 0.25\left(\pi(0.3\text{ m})^2/4\right)5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\left(400^4 - 97^4\right)\text{K}^4 = 25.6\text{ W.} \qquad <$$

(b) From an energy balance on the enclosure, radiative transfer heats the liquid nitrogen stream causing evaporation,

$$\dot{E}_{in} - \dot{E}_{out} = 0 \qquad q_{rad} - \dot{m}_{LN2} h_{fg} = 0$$

where $\dot{m}_{LN2}$ is the liquid nitrogen consumption rate. Hence,

$$\dot{m}_{LN2} = q_{rad}/h_{fg} = 25.6\text{ W}/125\text{ kJ/kg} = 2.05\times10^{-4}\text{ kg/s} = 0.736\text{ kg/h.} \qquad <$$

(c) If aluminum foil ($\varepsilon_p = 0.09$) were bonded to the upper surface of the baseplate,

$$q_{rad,foil} = q_{rad}\left(\varepsilon_f/\varepsilon_p\right) = 25.6\text{ W}(0.09/0.25) = 9.2\text{ W}$$

and the liquid nitrogen consumption rate would be reduced by

$$(0.25 - 0.09)/0.25 = 64\% \text{ to } 0.265\text{ kg/h.} \qquad <$$