ECE309

INTRODUCTION TO THERMODYNAMICS & HEAT TRANSFER

3 August 2004

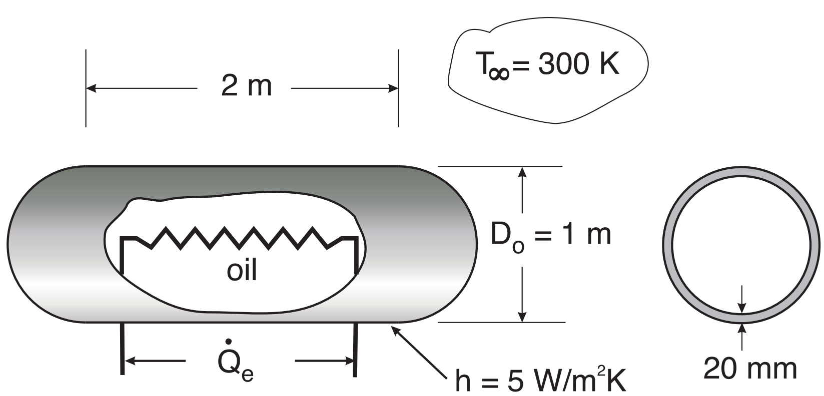
Final Examination R. Culham

- This is a 3 hour, closed-book examination.
- You are permitted to use one 8.5 in.$\times$ 11 in. crib sheet (both sides), Conversion Factors (inside cover of text) and the Property Tables and Figures from your text book.
- There are 5 questions to be answered. Read the questions very carefully.
- Clearly state all assumptions.
- It is your responsibility to write clearly and legibly.
- When using correlations, it is your responsibility to verify that all limiting conditions are satisfied.

Question 1 (20 marks)

An oil storage tank is designed to maintain the oil temperature at a uniform $400\ K$ by using a submerged resistance heating element. The storage tank consists of a cylindrical section that has a length of $2\ m$ and an outer diameter of $1\ m$ with the end caps being formed from two hemispherical sections as shown in the figure below. The tank is constructed from $20\ mm$ thick glass (pyrex, $k = 1.4\ W/m{\cdot}K$). The surrounding ambient air temperature is $T_\infty = 300\ K$ and the convective heat transfer coefficient over the full outer surface of the tank is $5\ W/(m^2 \cdot K)$. Assume 1-D conduction in both the cylindrical and hemispherical sections.

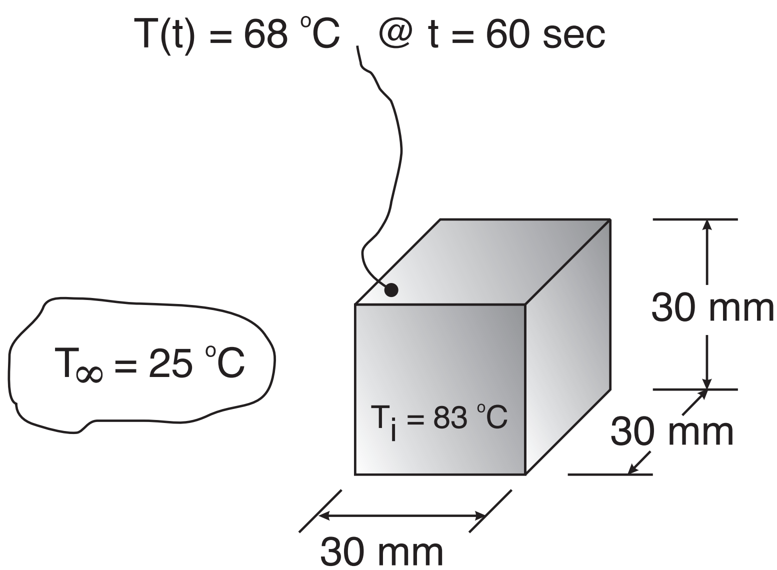
a) determine the electrical power, (W), that must be supplied to the heater to maintain these conditions.
b) the critical thickness of insulation for this tank can be determined for both the cylindrical and hemispherical sections. For the cylindrical section we know $r_{cr,cylinder} = k/h$. Set up the controlling equation used to determine $r_{cr,sphere}$ and show all calculations necessary to derive $r_{cr,sphere}$.



Question 2 (20 marks)

The convective heat transfer coefficient for air flow over a cuboid is to be determined by using the temperature versus time transient response. A pure copper cuboid with a length, width and height each equal to $\mathbf{30}\ \boldsymbol{mm}$ is uniformly heated to $\mathbf{83}\ °\boldsymbol{C}$ before it is inserted into an air stream having a temperature of $\mathbf{25}\ °\boldsymbol{C}$. Using a thermocouple located on the outer surface of the cuboid, we observe a temperature of $\mathbf{68}\ °\boldsymbol{C}$, $\mathbf{60}\ \boldsymbol{s}$ after the cuboid is inserted into the air stream.

Determine the convective heat transfer coefficient $(\boldsymbol{W/m^2 \cdot K})$, state all assumptions used to arrive at this conclusion and justify any assumptions where necessary.



Question 3 (20 marks)

Consider a room that is $\mathbf{4}\ \boldsymbol{m}$ long by $\mathbf{3}\ \boldsymbol{m}$ wide with a floor-to-ceiling distance of $\mathbf{2.5}\ \boldsymbol{m}$. The four walls of the room are well insulated, while the surface of the floor is maintained at a uniform temperature of $\mathbf{30}\ °\boldsymbol{C}$ using an electric resistance heater. Heat loss occurs through the ceiling, which has a surface temperature of $\mathbf{12}°\boldsymbol{C}$. All surfaces have an emissivity of $\mathbf{0.9}$.

a) determine the rate of heat loss, $(\boldsymbol{W})$, by radiation from the room.
b) determine the temperature, $(\boldsymbol{K})$, of the walls.

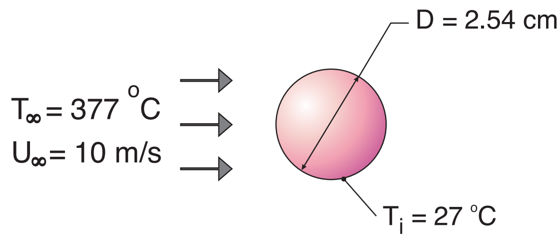
Question 4 (20 marks)

A new experimental resin is being developed for making canon balls. The resin which is initially formed into a spherical-shaped ball with a diameter of $D = 2.54\ cm$ and a uniform temperature of $27\ °C$ is cured by suddenly placing it in an air stream with an ambient temperature of $T_\infty = 377\ °C$ and an ambient flow velocity of $U_\infty = 10\ m/s$. The properties of the resin can be assumed to be:

$\rho_r = 2500\, kg/m^3$ $\qquad$ $(C_p)_r = 1100\, J/kg{\cdot}K$ $\qquad$ $k_r = 7.5\, W/m{\cdot}K$

If the resin cures at $175\ °C$

a) determine the rate of heat transfer, (W), required to cure the resin
b) how long, (s), will it take for the sphere to reach the cure temperature?



Question 5 (20 marks)

An electronic device is cooled by water flowing through capillary holes drilled in the casing as shown below. The temperature of the device casing is considered constant at $350\ K$. The capillary holes are $100\ mm$ long and $2.54\ mm$ in diameter. If water enters at a temperature of $320\ K$ and flows at a velocity of $0.2\ m/s$, calculate the outlet temperature of the water.

Note: Since the mean temperature of the fluid stream cannot be determined without already knowing the outlet temperature, use the inlet temperature of the fluid to calculate the fluid properties.