UNIVERSITY OF WATERLOO
DEPARTMENT OF MECHANICAL ENGINEERING
ME 353 HEAT TRANSFER 1

December 10, 1990 **Time: 9-12 a.m.**
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Three-hour Closed Book Final Examination. You are allowed one crib sheet (both sides). All questions are of equal value. State clearly and justify all assumptions made and label all sketches and thermal circuits clearly. Allocate your time wisely and do not spend disproportionate time on any single problem.

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PROBLEM 1

[20]

A three-step process for cooling of a sphere of radius $r_o = 5\ mm$ is to be analysed. The sphere is made of a special material ($\rho = 3000\ kg/m^3$, $k = 20\ W/m\ K$, $c = 1000\ J/kg\ K$, and $\alpha = 6.66 \text{ x } 10^{-6}\ m^2/s$) and is to be cooled from an initial temperature of $400^oC$ as described by the following three-step process:

(a) The sphere is cooled in air at $20^0C$ for a period of time, $t_a$, until the center temperature reaches a critical value, $T_a(0, t_a) = 335^0C$. This occurs in air and the heat transfer coefficient is estimated to be $h_a = 10\ W/m^2K$.

(b) The sphere is *insulated*, formed in a special die to a cube having side dimensions of $8.06\ mm$.

(c) The cube is cooled in a vigorous water bath at $20^oC$, where the convective heat transfer coefficient is estimated to be $h_w = 6000\ W/m^2C$, until the center of the cube cools to $50^oC$.

1. Calculate the time, $t_a$, required for the first step of the process to be completed.
2. Calculate the time, $t_w$, for the third step of the process to be completed.
3. Calculate the thermal energy loss during *each* process.

## PROBLEM 2

[20]

A block of material of thickness 20 $mm$ with known thermophysical properties ($k = 15\ W/m \cdot K$ $\alpha = 2.0 \times 10^{-5}\ m^2/s$) is imbedded in the wall of a channel that is initially at $25^oC$ and is suddenly subjected to a convection process with gases at $325^oC$. A thermocouple (TC) is installed 2 mm below the surface of the channel wall for the purpose of sensing the temperature-time history (following start-up of the hot gas flow) and thereby determining the transient heat flux. At an elapsed time of $10s$, the thermocouple indicates a temperature of $167^oC$.
Calculate the corresponding surface convective heat flux assuming the block is a semi-infinite solid.

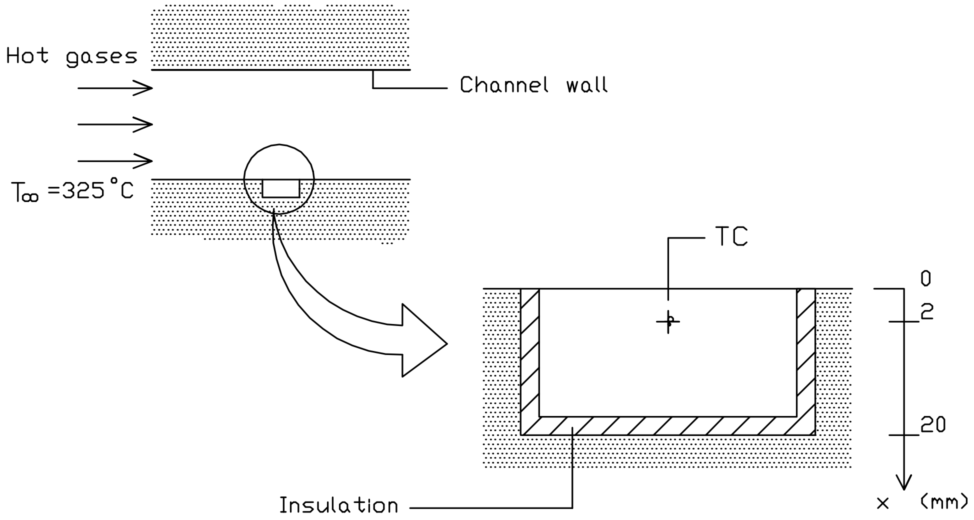


Figure 1

## PROBLEM 3

[20]

To determine air velocity fluctuations, it is proposed to measure the electric current required to maintain a platinum wire of 0.5 $mm$ diameter at a constant temperature of $77^oC$ in a stream of air at $27^oC$.

(a) Assuming Reynolds numbers in the range $40 < Re_D < 1000$, *develop* a relationship between the wire current and the velocity of the air which is in cross flow over the wire.

(b) Calculate the current required when the air velocity is 10 $m/s$ and the electrical resistivity of the platinum wire is $24 \times 10^{-6}\ \Omega - cm$.

(Problem 3 cont'd...)

You may use the empirical correlation due to Hilpert:

$$Nu_D = \frac{\overline{h}D}{k_f} = C Re_D^m \, Pr^{1/3}$$

where the correlation constants $C$ and $m$ are listed below:

| $Re_D$ | $C$ | $m$ |
|---|---|---|
| 0.4–4 | 0.989 | 0.330 |
| 4–40 | 0.911 | 0.385 |
| 40–4000 | 0.683 | 0.466 |
| 4000–40,000 | 0.193 | 0.618 |
| 40,000–400,000 | 0.027 | 0.805 |

PROBLEM 4

[20]

Under steady-state operation, the surface temperature of a small 20-W incandescent light bulb is $125^oC$ when the temperature of the room air and walls is $25^oC$. Approximating the bulb as a sphere 40 $mm$ in diameter with a surface emissivity of 0.8, what is the rate of heat transfer from the surface of the bulb to the surroundings? Discuss where the remaining heat loss goes.

PROBLEM 5

[20]

A diffuse, gray radiation shield of 60 $mm$ diameter and emissivities of $\epsilon_{2,i} = 0.01$ and $\epsilon_{2,o} = 0.1$ on the inner and outer surfaces, respectively, is concentric with a long tube transporting a hot process fluid. The tube surface is black with a diameter of 20 $mm$. The region interior to the shield is evacuated. The exterior surface of the shield is exposed to a large room whose walls are at $17^oC$ and experiences convection with air at $27^oC$ and a convection heat transfer coefficient of 10 $W/m^2 \cdot K$.

(Problem 5 cont'd...)

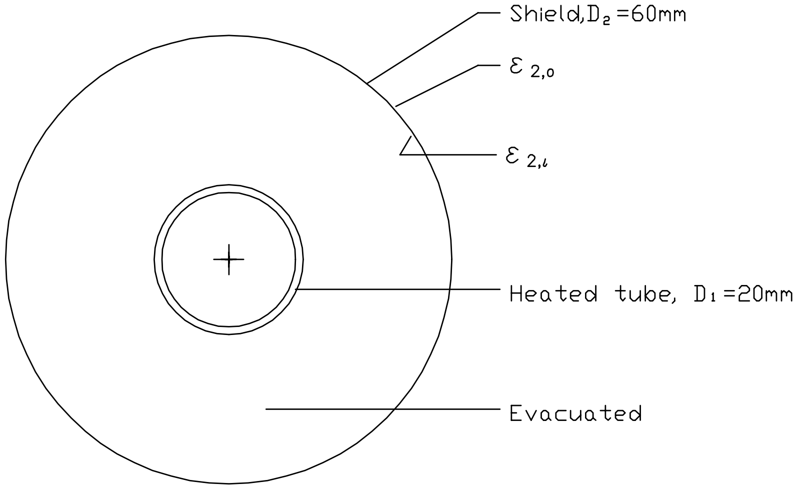


Figure 2

(a) Sketch and label clearly the radiation network inside the shield, and the thermal resistance circuit outside the shield. The shield is very thin and has high thermal conductivity, therefore its resistance can be neglected.

(b) Determine the operating temperature for the inner tube if the shield temperature is maintained at $42^oC$.