GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1995

Heat Transfer
EXAM AREA

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Assigned Number **(DO NOT SIGN YOUR NAME)**

-- **Please sign your name on the back of this page** --

Ph.D Preliminary Problem
HEAT TRANSFER
Fall 1995

1) Two long, metallic rods are joined together as shown in the figure. At the point that they are joined is a thin layer of a heat source that has a known generation rate of $\dot{q}$: The two rods are surrounded by air with a known convective heat transfer rate of h and a known ambient temperature of T_∞. Determine the following information:

   a) Derive the differential equation that can be used to determine the steady state temperature distribution in the rods. State any assumptions you make.

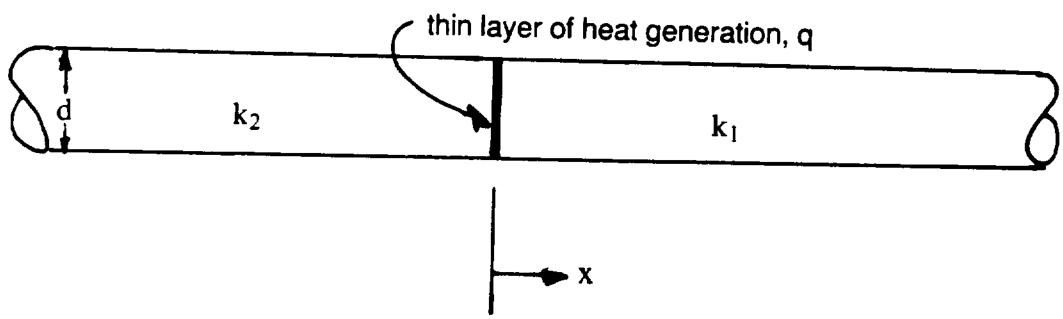
   b) Determine the dimensionless groups that determine the steady state temperature distribution in the rods.

   c) Give the boundary conditions for the differential equations.

   d) Determine expressions for the temperature distribution in the rods in terms of symbols shown in the figure.

   e) Determine expressions for the heat transfer rate along the length of the two rods in terms of symbols shown in the figure.

   f) Sketch both T(x) and q(x) for the case of $k_1 > k_2$.



air, h, T_∞.

2)

a. A special surface on a space shuttle has a spectral absorptivity of 0.9 in the interval $0<\lambda>2\mu m$ and zero at other wavelengths independent of surface temperature. It receives solar radiation at a rate of 900 W/m^2 and is maintained at 800 K. Consider the sun as a blackbody at 5800 K. Determine, per unit area of the surface,

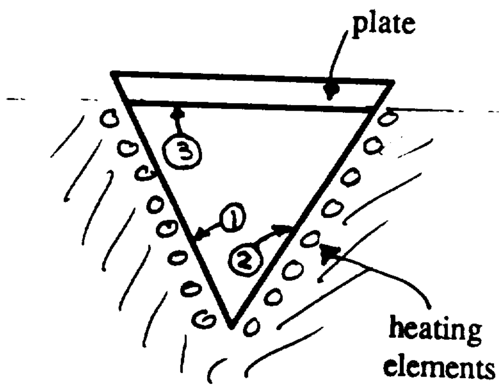
a) The rate of radiant energy absorbed by the surface.
b) The rate of radiant energy emitted by the surface.
c) The net rate of radiant energy transfer from the surface. Assume that the surroundings are at 0 K.

b.. A long V-groove shaped electric furnace is used to heat a thin metal plate as shown in the sketch. Heater surface 1 is black and has temperature $T_1 = 700K$. Heater surface 2 is diffuse and gray ($\varepsilon_2 = 0.9$). The bottom surface of the plate (surface 3) is diffuse and gray ($\varepsilon_3 = 0.8$) and is to be maintained at $T_3 = 450K$. The top surface is cooled primarily by convection (i.e. radiation is negligible on the top surface) with air at 27°C and the convective heat transfer coefficient is 75 W/m^2-°C. Assume that steady state exists and that all surfaces are isothermal and opaque.

Determine:

a) the net radiant heat transfer from the bottom surface of the plate.

b) the temperature of surface 2



c) the electric power input to heater 1

d) the electric power input to heater 2

(All sides are 1m wide and very long into the page)

Table 12.1 Blackbody radiation functions[a]

λT ($\mu m \cdot K$)	$F_{(0 \rightarrow \lambda)}$	λT ($\mu m \cdot K$)	$F_{(0 \rightarrow \lambda)}$
200	0.000000	7,000	0.808109
400	0.000000	7,200	0.819217
600	0.000000	7,400	0.829527
800	0.000016	7,600	0.839102
1,000	0.000321	7,800	0.848005
1,200	0.002134	8,000	0.856288
1,400	0.007790	8,500	0.874608
1,600	0.019718	9,000	0.890029
1,800	0.039341	9,500	0.903085
2,000	0.066728	10,000	0.914199
2,200	0.100888	10,500	0.923710
2,400	0.140256	11,000	0.931890
2,600	0.183120	11,500	0.939959
2,800	0.227897	12,000	0.945098
2,898	0.250108	13,000	0.955139
3,000	0.273232	14,000	0.962898
3,200	0.318102	15,000	0.969981
3,400	0.361735	16,000	0.973814
3,600	0.403607	18,000	0.980860
3,800	0.443382	20,000	0.985602
4,000	0.480877	25,000	0.992215
4,200	0.516014	30,000	0.995340
4,400	0.548796	40,000	0.997967
4,600	0.579280	50,000	0.998953
4,800	0.607559	75,000	0.999713
5,000	0.633747	100,000	0.999905
5,200	0.658970		
5,400	0.680360		
5,600	0.701046		
5,800	0.720158		
6,000	0.737818		
6,200	0.754140		
6,400	0.769234		
6,600	0.783199		
6,800	0.796129		

3)

In an engineering application, a heat sink is created by having an aluminum block with a number of holes, having L/D ratio of 30, through which the coolant liquid can be passed in order to remove the heat.

a. Does this arrangement represent one of the constant surface heat flux case or the constant surface temperature case? Explain your thinking. In general, briefly state the engineering significance you attach for these two cases.

b. In the above arrangement, the following information is gathered. Diameter of hole 1 in.; mean velocity 3 ft/sec. The thermophysical properties of the fluid at mean temperature of 70°F is as follows:

Density (ρ) = 62.3 lbm/ft^3
Dynamic viscosity (μ) = 2.36 lbm/hr ft
Specific heat (c_p) = 1.00 B/lbm F
Thermal conductivity (k) = 0.343 B/hr ft F.
The surface temperature is 150°F.
Dynamic viscosity of fluid at surface temperature (μ_s) = 1.05 lbm/hr ft at 150°F.

The following correlations are made available:

(1) $Nu = 0.023\,\mathrm{Re}_d^m\,\mathrm{Pr}^n$

(2) $Nu = 0.027\,\mathrm{Re}_d^m\,\mathrm{Pr}^n(\mu/\mu_s)^{.14}$

(3) $Nu = 0.036\,\mathrm{Re}_d^m\,\mathrm{Pr}^n(\mu/\mu_s)^{.14}(D/L)^{1/18}$

m = 0.8, n = 1/3 (for all three correlations)

(i) Determine the expected heat transfer coefficient using each of the three correlations.

(ii) Explain the differences in your answers by reviewing possible flow patterns in the hole resulting in these correlations. Draw simple sketches illustrating your observations.

c. Estimate the maximum amount of heat removed by the coolant per hole as well as the inlet and exit temperature of the coolant.

d. Considering our understanding of the flow in the entrance region of the hole and its impact on the heat transfer coefficient, how would you modify Eq. 3 in part (b)?

e. Suggest effective ways to improve heat removal capabilities. **Do not change the size of the block, the mass flow rate of heat transfer fluid and the block temperature as well as entering fluid temperature you have evaluated in part (c).**

Time permitting, demonstrate that your choices will indeed meet the specified objective by recognizing trends and without any calculations.