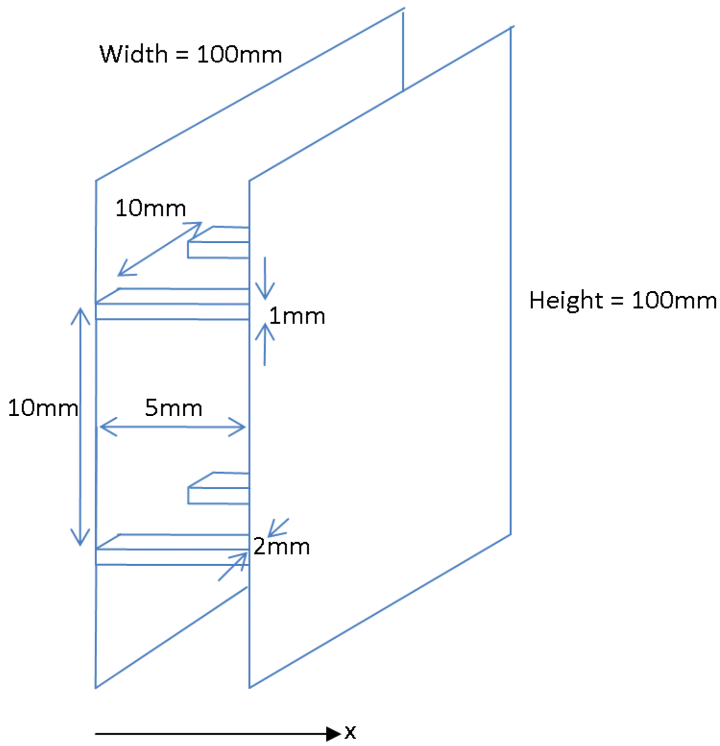
Written Ph.D. Qualifying Examination (Heat Transfer)

Fall 2009

1. A set of eighty one rectangular cross-section, stainless steel fins connect between two copper plates, with dimensions shown below. A current of 1 amp is flowing through the structure in the x-direction.



Assume each copper plate is at a uniform temperature. The plate at x=0 is at a higher temperature than the other one which is at the ambient temperature of 300 K.

Fins repeat with period of 10 mm.

Assume uniform h of 5 W/m^{2}K from the fins and constant ambient air temperature of 300 K.

Thermal conductivity of air is 26E-3 W/mK   Thermal conductivity of steel is 15 W/mK

<u>Note:</u> only four fins are shown in the figure, but there are a total of eighty one present in the structure.

Given that the electrical resistivity of the stainless steel is 1 micro-ohm–m estimate the heat generation rate per unit volume in the stainless steel. Note that the air flow is sealed around the edges of the plates so the air can not escape from the gap.

(A) Determine an expression for the temperature as a function of (x) along the stainless steel fins and an expression for the location and magnitude of the maximum temperature. Find numerical values for these.

(B) Calculate the thermal resistance of the fin when the gap between the plates is filled with air.

(c) Estimate the thermal resistance of the fin when the air gap is evacuated.

Clearly state any assumptions.

2. In a cylindrical pipe through which liquid is flowing, the velocity and temperature distribution over a cross section were measured, and it was found that both were parabolic. Thus,

$$\frac{u(r)}{u_o} = 1 - \left(\frac{r}{r_o}\right)^2$$

where u_o = centerline velocity, r_o = pipe radius

and

$$\frac{T(r,x) - T_s(x)}{T(0,x) - T_s(x)} = 1 - \left(\frac{r}{r_o}\right)^2$$

where T_s is the temperature of the fluid at the wall.

It can be shown that in such a case, the Nusselt number is a constant integer value less than 10. Find this value.

Note: If convenient, you may declare $\tilde{r} = r/r_o$ and these relevant temperature differences:

local $\theta(r,x) = T(r,x) - T_s(x)$

mean $\theta_m(r,x) = T_m(x) - T_s(x)$

centerline $\theta_o(0,x) = T(0,x) - T_s(x)$

3. A bank of tubes needs to be maintained at a constant surface temperature of 600 K to heat the gas flowing inside each tube. The tubes are of diameter D= 10 mm, separated by a distance s = 30 mm. They are heated by placing them inside a long radiative heating arrangement consisting of two parallel plates. The top plate is insulated to prevent any heat loss through the system. The bottom plate needs to be kept at 1200 K to provide sufficient radiant heat to the bank of tubes. A heating element is inserted inside the bottom plate to provide the required heat flux of q'' W/m^2 (assume unit depth) on the plate. The top surface of the bottom plate has spectral emissivity ε_λ =

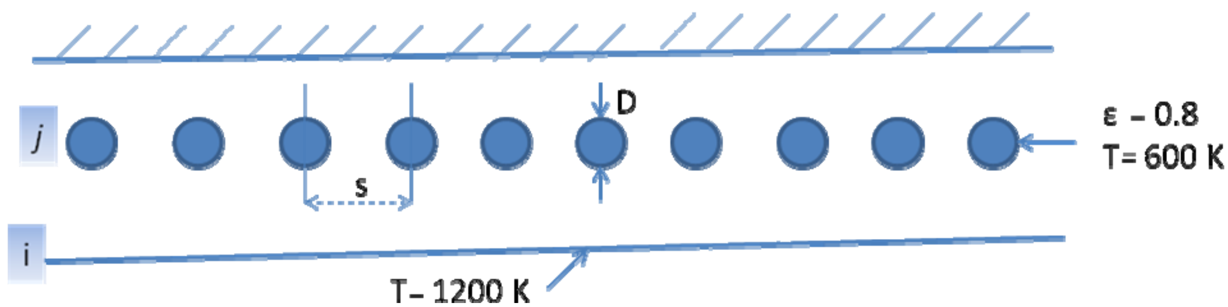
0.8 for $\lambda < 3$ μm and $\varepsilon_\lambda = 0.2$ for $\lambda > 3$ μm. The emissivity of tubes surface and top insulated

plate is $\varepsilon = 0.8$. The view factor between an infinite plane and row of tubes can be given as:

$$F_{ij} = 1 - \left[1 - \left(\frac{D}{s}\right)^2\right]^{0.5} + \left[\left(\frac{D}{s}\right)\tan^{-1}\left[\left(\frac{s^2 - D^2}{D^2}\right)^{0.5}\right]\right]$$

(a) List your assumptions and estimate the heat flux q'' that must be provided by heating element inserted inside the bottom plate to maintain it at the desired temperature. **(80%)**

(b) The emissivity of the top plate is changed to 0.3. How does it effect the required heat flux q'' ? **(20%)**



Blackbody Radiation Functions

λT (μm · K)	$F_{(0\rightarrow\lambda)}$
1,400	0.007790
1,600	0.019718
1,800	0.039341
2,000	0.066728
2,200	0.100888
2,400	0.140256
2,600	0.183120
2,800	0.227897
2,898	0.250108
3,000	0.273232
3,200	0.318102
3,400	0.361735
3,600	0.403607
3,800	0.443382
4,000	0.480877