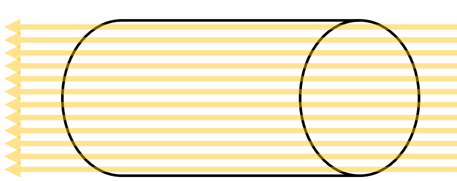
Ph.D. Qualifying Examination (Heat Transfer)

Spring 2015

1. A glass cylinder with radius R = 4 cm experiences a large, uniform flux of light = 1 MW m^{-2}. When this flux is multiplied by the absorption coefficient α, which has units of m^{-1}, the product represents the average uniform volumetric heat absorption experienced throughout the glass cylinder (i.e., MW m^{-3}). The glass cylinder is actively cooled via air convection around the outsides and can be treated as semi-infinite in length, such that heat transfer from the front and back edges can be ignored. Furthermore, the cooling can be approximated as angular symmetric around the outside of the cylinder, and the air temperature can be assumed as a constant T_{inf} = 30°C. The effective (convective + radiative) heat transfer coefficient between the glass and surrounding air is 50 W m^{-2} K^{-1} and the glass thermal conductivity is essentially constant at 1.5 W m^{-1} K^{-1} over the entire temperature range being analyzed.
   a) Write a steady state energy balance equation for the glass cylinder, and the appropriate boundary conditions that should be applied to determine the temperature distribution in the glass cylinder. **(2 points)**
   b) Solve the governing equation to determine the steady state temperature distribution in the glass as a function of the glass absorption coefficient α. **(5 points)**
   c) Determine the location in the glass where the temperature will be highest and write the appropriate condition (e.g., as an equation) to determine the maximum acceptable absorption coefficient (in units of m^{-1}), assuming the maximum temperature cannot exceed 900°C anywhere in the glass. **(3 points)**

$$\kappa\nabla^2 T = \frac{\kappa}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\kappa}{r^2}\frac{\partial}{\partial \phi}\left(\frac{\partial T}{\partial \phi}\right) + \kappa\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right)$$

Glass Concentrator



Uniform Incoming Light Rays 1 MW m^{-2} Flux

Partial Absorption α (m^{-1}) as Light Rays Pass Through Glass

2. Consider low-speed, constant-property, fully developed laminar flow between two parallel plates at $y = \pm b$. One plate is insulated (at y = b) and the other is isothermal (at T_s.) The velocity is high enough for ***viscous dissipation,*** $\mu \left[\frac{du}{dy}\right]^2$***, to be significant***.

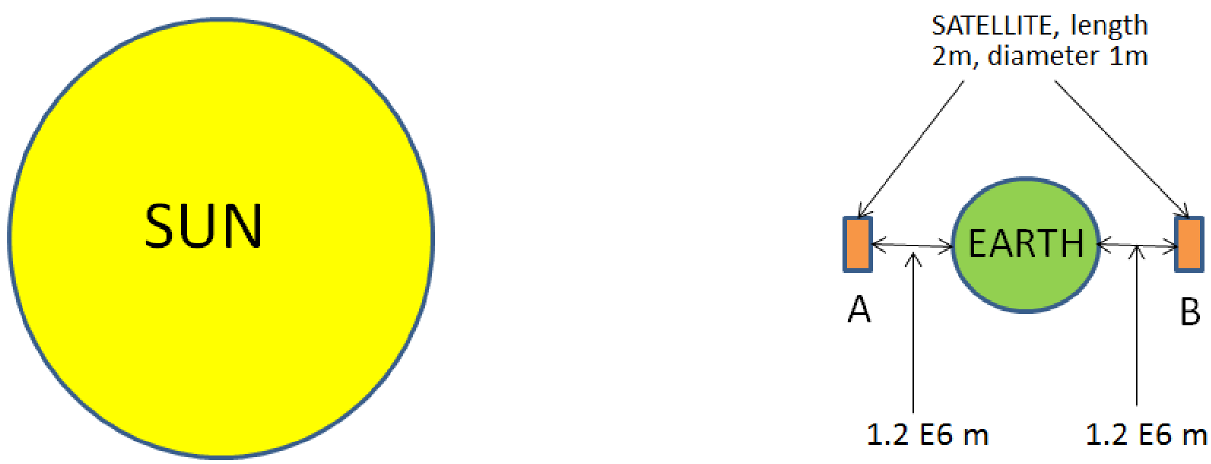
a) Derive an expression for the velocity (u) profile in terms of the vertical coordinate y, spacing b, and the bulk velocity, u_b. **(3 points)**

b) Write the thermal energy conservation equation for this problem **(1 point)**

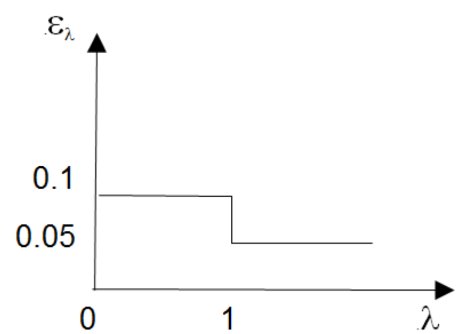
c) At large x, i.e., a long distance from the inlet, apply energy balance considerations and the provided boundary conditions to state descriptively, as well as with an appropriate simple equation, what must hold true about the bulk temperature of the fluid. **(2 points)**

d) Determine the temperature (T) profile as a function of T_s, y, b, μ, k, and u_b at these large distances from the inlet. **(4 points)**

3.



A cylindrical satellite orbits around the earth at the equator as shown. At point A it is exposed to direct solar radiation while at point B, it is shielded from direct solar irradiation by the earth, which is at 300K. The satellite is also generating 100 W of power and can dissipate it by radiating to outer space. Compare the temperature of the satellite at positions A and B. The satellite has the following spectral emissivity and it is diffuse.



Diameter of sun = 1.4×10^9 m

Temperature of sun = 6000 K

Diameter of earth = 1.3×10^7 m

Temperature of earth = 300 K

Orbit distance of earth from sun = 1.5×10^{11} m

a) Calculate the angle factors between the sun and satellite at position A and the earth and satellite at position B. **(2 Points)**
b) Calculate the irradiation G arriving on the surface of the satellite in position A and B. **(3 Points)**
c) Calculate the emissivity and solar absorptivity of the satellite in position A and B. **(2 Points)**
d) Calculate the temperature of the satellite in position A and B. **(3 Points)**

Assume the satellite temperature does not exceed 85 deg C

Angle Factor = (Irradiation arriving at object from source)/ (Total radiosity of source)

$$F_{ij} = \frac{1}{A_i} \int_{A_j}\int_{A_i} \frac{\cos\theta_i \cos\theta_j}{\pi R^2} dA_i dA_j$$

Blackbody Radiation Function

λT (μmK)	F(0-λ)
1200	0.00213
1400	0.00779
1600	0.01972
1800	0.03934`
2000	0.06673
2200	0.10089
2400	0.14026
2600	0.18312
2800	0.22790
3000	0.27323
3200	0.31810
3400	0.36174
3600	0.40361
3800	0.44338
4000	0.48088
5000	0.63375
6000	0.73782
7000	0.80811
8000	0.85630
9000	0.89003
10000	0.91420
11000	0.93189
12000	0.94510
13000	0.95514
14000	0.96290
15000	0.97000