Student #_____

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Ph.D. Qualifying Examination *in* ***Heat Transfer***

- One open book.
- Answer questions 1 and 4 and either of 2 or 3
- All questions carry the same weight (33.3 % of the exam).

Exam prepared by

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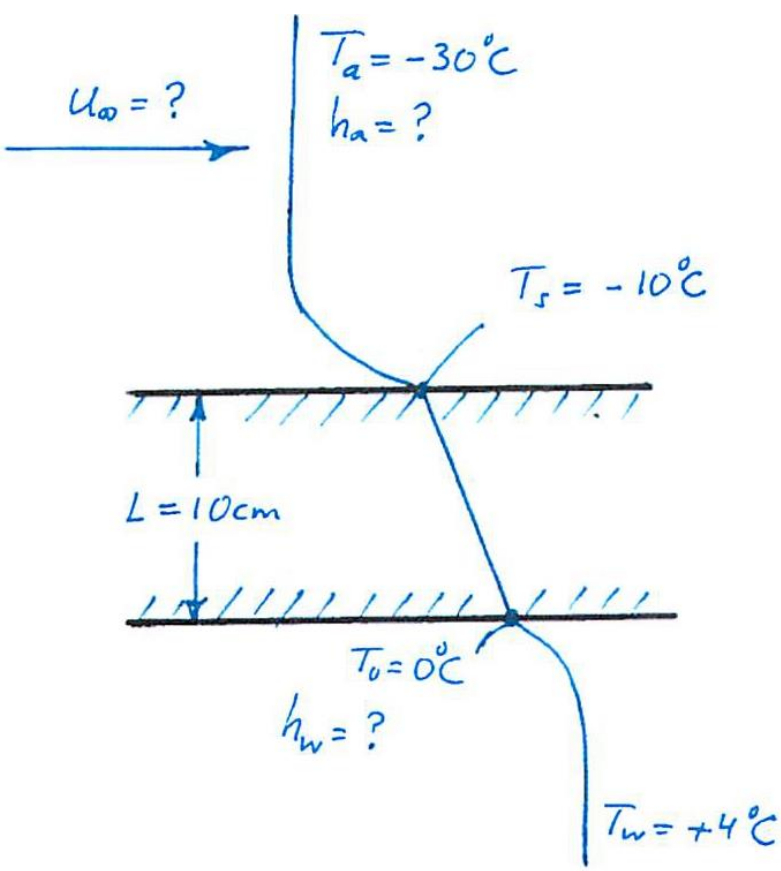
<u>Question 1: Skating on the lake:</u> During winter the surface of a slowly flowing lake on Long Island in Yaphank, NY (which is actually the dammed Carmen's river) develops a layer of *10 cm* thickness. Known are the lake water temperature, $T_w = 4°C$, the temperature of the underside of the ice layer, $T_o = 0°C$, the temperature of the atmospheric air, $T_a = -30°C$, and the temperature of the ice surface for the skaters, $T_s = -10°C$. The ice thermal conductivity is *2.25 W/m-K*. You do not need to make any additional assumptions about the nature of the ice sheet or the flows of the air and water on either side of the ice.

a. Calculate the convective heat transfer coefficients in the air and in the water for both flows over the ice.

b. Use the air convective transfer coefficient to determine the air speed U_∞. Is the air boundary layer laminar or turbulent?



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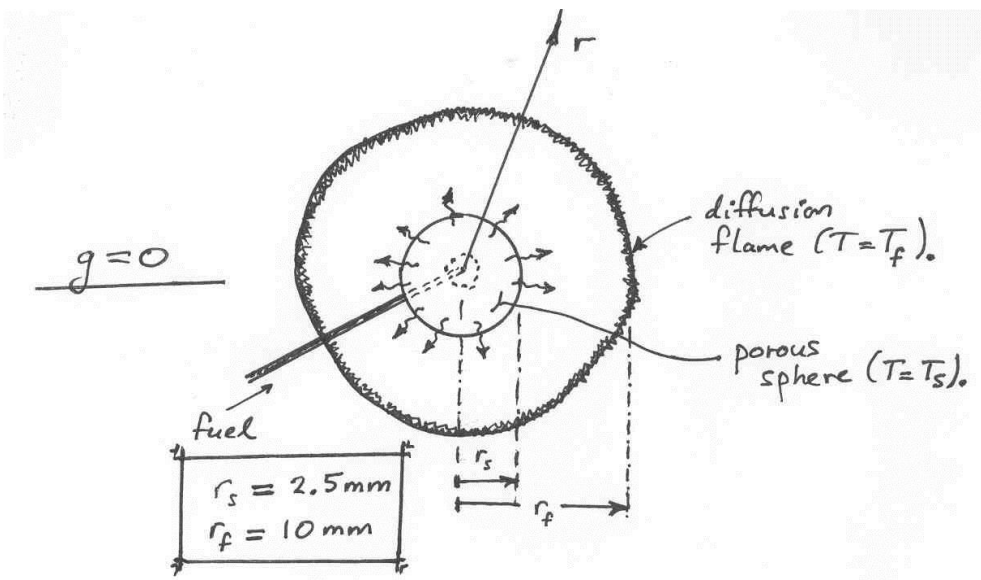
<u>Question 2: A porous combusting sphere:</u> Consider a porous fuel sphere burning in a quiescent *zero-gravity* infinite atmosphere. We shall examine the heat conduction process for this problem. Gaseous fuel (e.g., propane) is fed through a small tube into the center of the porous sphere. The fuel flows to the surface of the sphere, then into the gas outside and finally into the flame, where it reacts with surrounding oxidizer. See the figure below. The sphere and flame radii as are given in this figure. Use $T_f = 2000K$, $T_s = 400K$ and $T_\infty = 300K$.



Assuming constant gas conductivity $k = 75 \times 10^{-3}$ *W/m-K (*air at ~ *1200K)*, solve the steady-state heat conduction equation:

a. Between the flame and the sphere;
b. Between the flame and the ambient;

The use these solutions to determine the following physical quantitites:

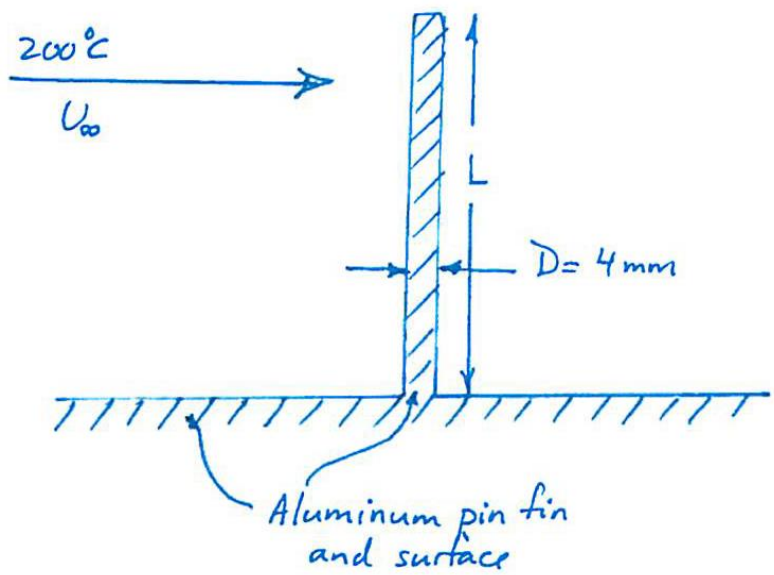
c. The TOTAL heat flux from the flame (units W/m^2) to the porous sphere side and the ambient air side;
d. The flame heat generation rate (units *W*).

Answer the following question:

e. Will the temperature field between the flame and the ambient ever achieve a finite-time steady state (*essay* answer)? Why or why not?

<u>Question 3: Heating a pin fin:</u> A pin fin of average temperature 100 °C extends into a 1 m/s uniform air stream of temperature 200 °C. The pin fin diameter is 4 mm.

a. Calculate the average heat transfer coefficient between the pin fin and the surrounding air.
b. Using the heat transfer coefficient from part (a), employ a lumped heat transfer approach calculate the time required to heat the pin fin from 100 °C to 195 °C.
c. Repeat the calculation of the heat transfer coefficient in (a) and the calculation of the time required to heat the pin fin to 195 °C in (b) when the air flow speed is 100 m/s.



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<u>Question 4: Spreading forest fire:</u> Consider radiant heat transfer from a spreading forest fire. Forest fires are large scale events where almost all of the heat transfer to the unburned fuel occurs by flame radiation as shown in the figure below. We shall describe the flame (surface 2) as a hot (2000 K), radiating vertical black body wall (on infinite depth) of height *a*, displaced from the surface of the fuel bed by a distance *b* ("surface" 3), and the unburned fuel in front of the flame as a flat surface (surface 1) of infinite depth and length *w*. The fuel surface is non-emitting. The view factor from the surface (1) to the flame (2) is given by:

$$F_{1\text{-}2} = \{A+(1+B^2)^{1/2} - [(A+B)^2 + 1]^{1/2}\}/2,$$

where $A = a/w$ and $B = b/w$. Using this result, calculate the radiant heat flux from the *flame* to the *surface*.

Consider the case $B = 0$. Draw the flame-to-surface flux distribution as *w* increases compared with the fixed flame height *a*. Assume reasonable values for *w* and a reasonable range of variation of *w*.