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Ph.D. Qualifying Exam in Heat Transfer

- One open book.
- Answer all questions.
- All questions carry the same weight.

Exam prepared by

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Problem 1:

1. A *2 cm* thick stainless steel tank wall is *1m x 1m*. On the inside is water boiling at *1 atm*. The other side of the wall is exposed to ambient air at *40°C* and distant surroundings at *20°C*. Calculate the heat transfer through the wall. What is the dominant mode of heat transfer?

Problem 2:

2. A *0.1 mm* diameter copper wire is used as a hot-wire anemometer. It dissipates *0.05 W/m* in a *20°C* ambient air. Calculate the velocity of the air normal to the wire and the temperature of the wire.

Problem 3:

Consider a porous fuel sphere burning in a quiescent *zero-gravity* infinite atmosphere. We shall examine both the steady and unsteady heat conduction problems for this process. For the porous sphere, 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 $T_\infty = 300K$.

Figure for # 3: The droplet conduction problem.
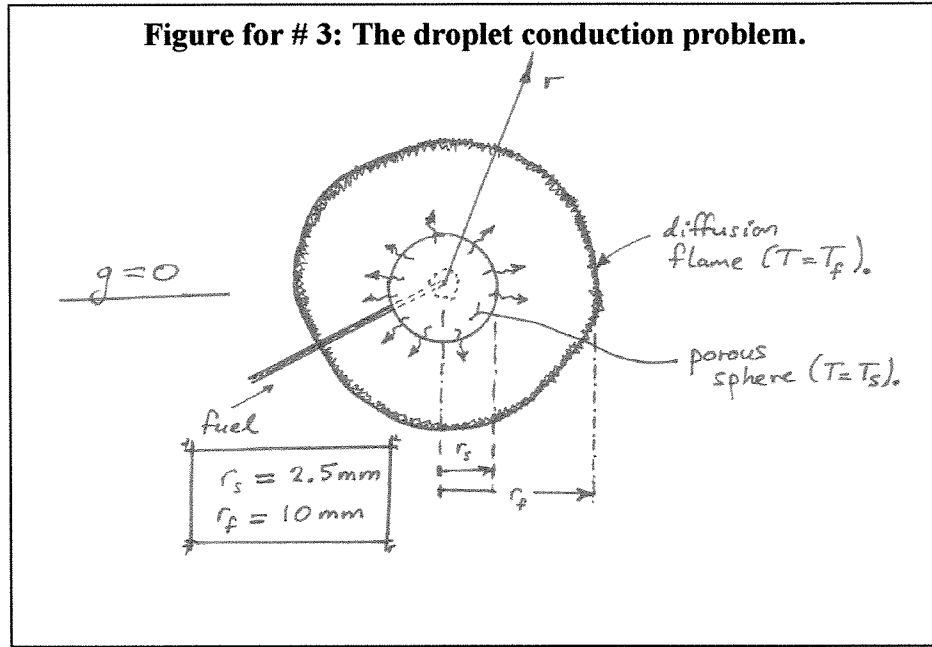
a) Assuming constant gas conductivity $k = 75 \times 10^{-3}$ W/m-K (air at ~ 1200K), solve the steady-state heat conduction equation *(i)* between the flame and the sphere; *(ii)* between the flame and the ambient. Use these two solutions to calculate *(iii)* the heat flux from the flame (W/m^2), and *(iv)* the flame heat generation rate (W).

b) Solve the unsteady start-up problem between the porous sphere surface and the flame, using $T(r,0) = T_\infty$ as the initial temperature everywhere. At time $t = 0^+$ the temperature at at r_f is impulsively raised to $T_f = 2000K$ while the surface **remains at** $T_\infty = 300K$ (this is a simplification of the problem).

c) Will the temperature field in the region outside the flame ever achieve a finite-time steady state (*essay* answer)?

Problem 4:

For the candle flame shown below the flame is a perfect sphere and the wax surface beneath the flame is perfectly flat. Please answer the following questions:

a) Find the configuration or view factor from the flame to the wax surface beneath it. Assume an infinitesimal wick that provides no obstruction, $\delta \to 0$.

b) Why doesn't the view factor in (a) depend upon the flame radius R?

c) Calculate the net heat flux to the wax. Use flame temperature $T_f = 1400\,°C$, liquid wax temperature $T_w = 75\,°C$ and ambient temperature $T_\infty = 22\,°C$. Use $a = 5\ mm$, $R = 2\ mm$, and $r = 7.5\ mm$.

Figure for # 4: The candle flame. Ignore gravitational influences that cause the actual teardrop shape and focus instead on the small flame itself.