M.E. Ph.D. Qualifier Exam
Spring Semester 2002

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Semester 2002

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—**

Problem 1

Consider the forced, laminar flow of a viscous liquid through a circular pipe with radius R_0, where the wall temperature, T_w is a constant. Viscous dissipation tends to warm up the fluid, and this warming effect is offset by cooling at the wall, so that the flow is thermally and hydrodynamically fully developed. Consequently the momentum and energy conservation equations are:

$$\mu \frac{1}{r}\frac{d}{dr}\left(r\frac{du}{dr}\right) - \frac{dP}{dx} = 0$$

$$k \frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \mu\Phi = 0$$

$$\Phi = \left(\frac{du}{dr}\right)^2$$

where Φ represents viscous dissipation. Prove that wall the heat flux can be represented by the following equation, and derive an expression for the constant A:

$$q'' = A\left(-\frac{dP}{dx}\right)^2$$

Problem 2:

Consider radiant heating furnace (dimensions H, W, and L are known) that is used for heating metal sheet (load) that is being transported through the furnace on the conveyer belt with the constant speed U_0. The simplified schematic of the physical arrangement is shown in the figure below. There are total N radiant heaters installed on the crown of the furnace, which are used to supply radiant energy to the metal sheet. The operating temperatures, positions, and dimensions of the heaters are known, as well as their radiative properties. The dimensions and thermophysical properties of the metal sheet are also known. The furnace is filled with nitrogen to avoid metal oxidation during heating. You are charged with finding the temperature distribution established at the top surface of the metal sheet as it travels through the furnace.

The closed-form solution of the problem is not required, however just (1) identify all important modes of heat transfer, (2) formulate the problem in terms of **relevant parameters** energy balance, (3) make <u>all</u> appropriate assumptions and <u>justify</u> them, (4) state the boundary and initial conditions, and (5) discuss how you'll go about finding the solution (in a few words).

<u>Word of wisdom</u>: Don't freak out!!! Spend a few minutes just thinking about the problem and key phenomena that need to be accounted for, and only then proceed to writing! Remember, this problem can be solved in many possible ways depending upon the assumptions you make...so be sure to back every step of your analysis by appropriate assumptions.

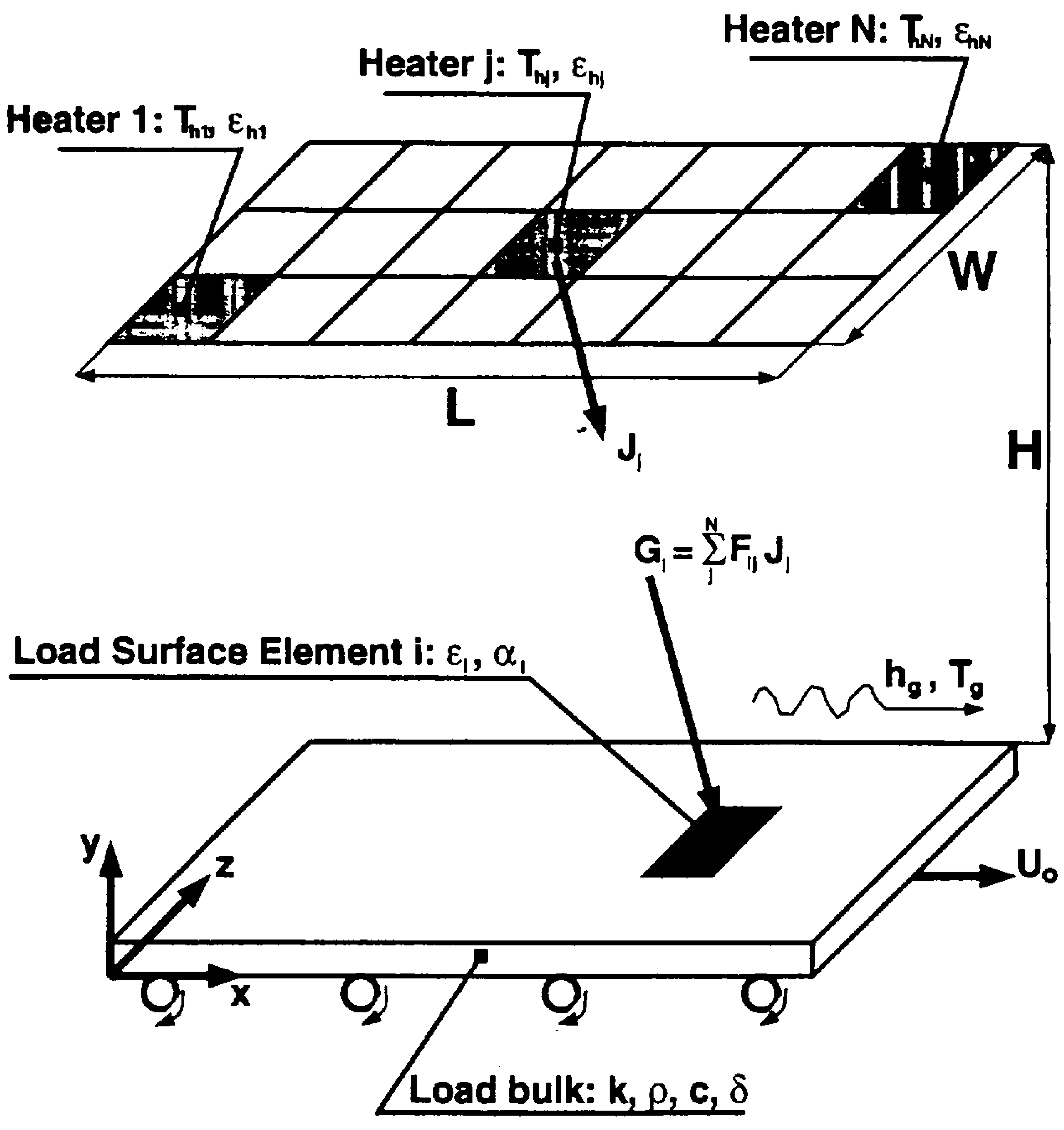

Figure 1: Schematic of radiant heating process

Question 3:

A lead sphere 1.5 mm in diameter is initially at a temperature of 200 deg. C is suddenly exposed to a convective environment at temperature of 100 deg.C. If the convection coefficient is 500 W/m^2 K, estimate the temperature of the center of the sphere after 3 seconds.

If the sphere is then transferred to an oil bath with convection coefficient of 5000 W/m^2 K at a temperature of 300 deg. C estimate how long it will take for the surface to heat up again to 200 deg. C.

Density of lead = 11340 kg/m^3
Specific heat of lead = 129 J/kg.K
Thermal conductivity of lead = 35.3 W/m.K

Acceleration due to gravity 9.8 m/s^2

Properties of oil at 200 C:
Thermal conductivity of oil = 132 W/m.K
Density of oil = 806 kg/m^3
Dynamic viscosity of oil = 0.47 $N.s/m^2$
Specific heat of oil = 2471 J/kg.K
Prantl number 88
$\beta = 0.7$

Biot # = $h r_o / k$ Fo = $\alpha t / r_0^2$

For a sphere solution to temperature distribution is of the form:

$$\frac{T - T_\infty}{T_i - T_\infty} = \frac{\theta_0^*}{\xi_1 r^*}\sin(\xi_1 r^*) \quad \theta_0^* = C_1 \exp(-\xi_1^2 Fo) \quad \text{where } r^* = \frac{r}{r_0} \quad \text{and} \quad \theta_0^* = \frac{T_0 - T_\infty}{T_i - T_\infty}$$

Bi = h r / k	ξ_1	C_1
0.2	0.760	1.060
0.25	0.845	1.074
0.3	0.921	1.088
0.4	1.053	1.116
0.5	1.166	1.144
0.6	1.264	1.171
0.7	1.353	1.198
0.8	1.432	1.224
0.9	1.504	1.249
1.0	1.571	1.273
2.0	2.023	1.479
3.0	2.289	1.623
4.0	2.456	1.720
5.0	2.570	1.788
6.0	2.654	1.934
7.0	2.717	1.867
8.0	2.765	1.892
9.0	2.804	1.910
10.0	2.836	1.930
20.0	2.986	1.978
30.0	3.037	1.990
40.0	3.063	1.994
50.0	3.079	1.996