GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Semester 2002

Heat Transfer
EXAM AREA

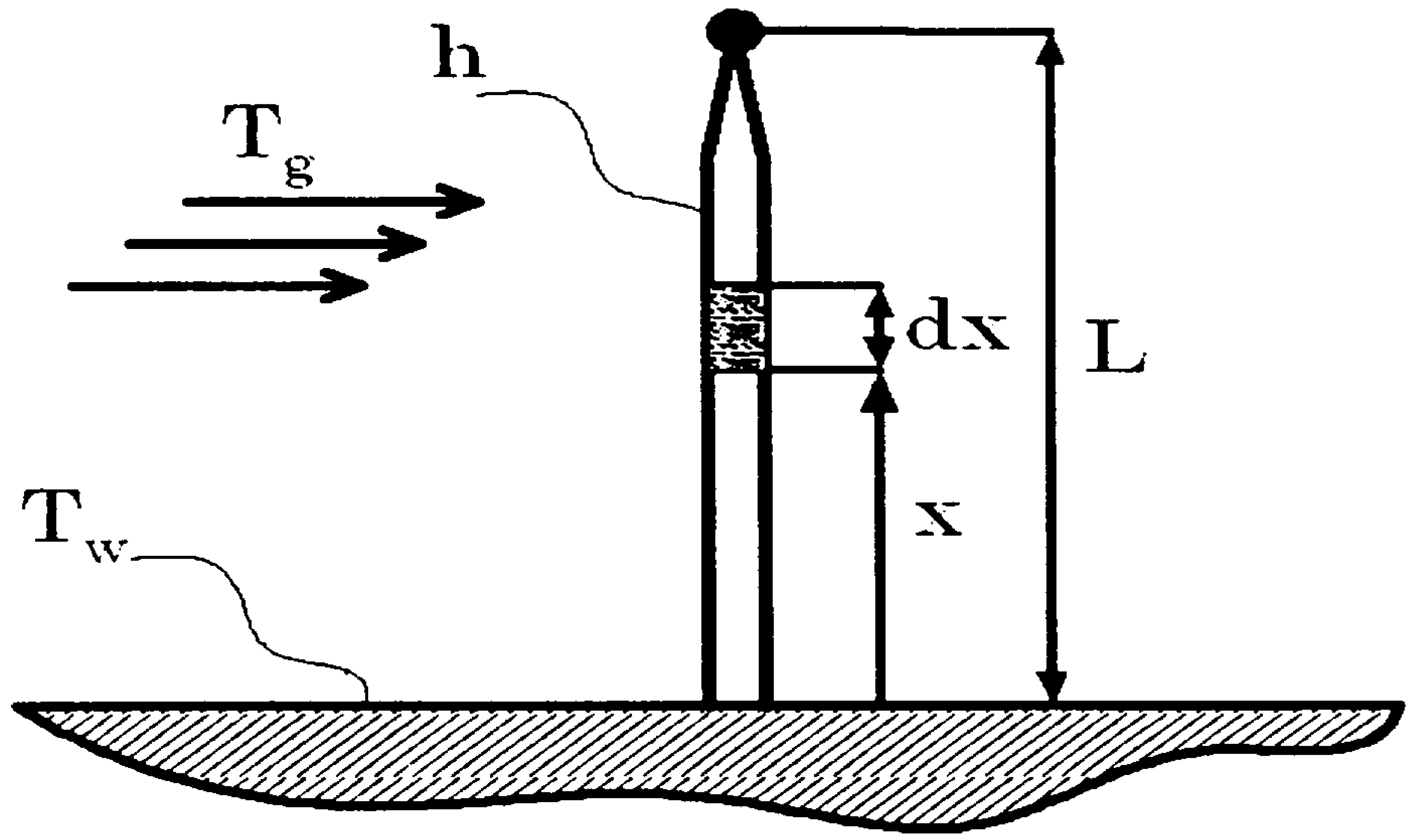
Assigned Number (DO NOT SIGN YOUR NAME)

- **Please sign your name on the back of this page—**

Ph.D. Qualifying Examination, Fall 2002
Heat Transfer

1. It is necessary to estimate the conduction and radiation errors in the measurement of the gas temperature. The physical arrangement is illustrated in the sketch below. A temperature sensor (a shielded thermocouple with wires inside and outer radius of the insulating shield equal to r) protrudes into a gas stream a known distance (L) from the wall. The heat transfer coefficient (h) between the gas stream and the thermocouple is assumed to be known, as well as geometry and thermophysical properties of the thermocouple are given. The temperatures of the wall (T_w) and of the flowing gas (T_g) are also known.

(1) Derive an expression for the temperature distribution along the thermocouple.
(2) Determine the temperature of the thermocouple junction (T_{tc}).
(3) If conduction heat transfer along the thermocouple is negligible, what is the temperature of the thermocouple junction (T_{tc}).
(4) Sketch the variation of the thermocouple error defined as $(T_g-T_{tc})/(T_g-T_w)$ as a function of the wall temperature T_w for the worst case (i.e., free convection heat transfer with very small heat transfer coefficient h) with emissivity of the thermocouple as a parameter.



2. Pressurized liquid water enters a nuclear reactor with a mass flow rate $\dot{m}$. The reactor is in the shape of a hollow circular cylinder of inside diameter D_i and outside diameter D_o. The nuclear fuel generates heat at a rate q''' (W/m^3) uniformly throughout and is well insulated on the outside. The average temperature of the water as it flows through the reactor must be T_W when the reactor heat transfer rate is q_R.

(a) Draw a sketch depicting the average water temperature as a function of axial position.

(b) Develop an appropriate analysis that could be used to determine the temperature of the water entering (T_C) and leaving (T_H) the reactor.

3. A lead sphere 15 mm in diameter, initially at a temperature of 200 °C is suddenly exposed to a convective environment at temperature of 100 °C.

(a) If the convection coefficient is 500 W/m^2 K, **estimate the temperature of the center** of the sphere after 3 seconds.

(b) If the sphere is then transferred to an oil bath with convection coefficient of 10,000 W/m^2 K at a temperature of 300 °C **estimate how long it will take for the surface to heat up** to 200 °C.

Properties of lead at 150 °C
Density of lead = 11340 kg/m^3
Specific heat of lead = 132 J/kg.K
Thermal conductivity of lead = 34 W/m.K

Acceleration due to gravity 9.8 m/s^2

Properties of oil at 200 °C:
Thermal conductivity = 0.132 W/m.K
Density = 806 kg/m^3
Dynamic viscosity = 0.47 N.s/m^2
Specific heat = 2471 J/kg.K
Prandtl number 88
$\beta = 0.7 \times 10^{-3}$ K^{-1}

Biot number = $h\, r_0 / (3\, k)$ Fo = $\alpha\, t / r_0^2$

The first term in the infinite series solution for transient temperature distribution in a sphere is given by:

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

Bi = $h\, r_o / (3\, k)$	First Eigenvalue ξ_1	Constant 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