Ph.D. Qualifying Examination
HEAT TRANSFER-Closed Book

Identification Number: ____________________________________
(Please also indicate your identification number on subsequent pages.)

Instructions: Two hours are allotted for the exam. Point values for each problem are indicated below. Only fundamental concepts and equations are required for each problem. An equation sheet is therefore not provided. If a convection correlation is needed that is not provided, define a suitable form in terms of appropriate dimensionless groups. All parameters and symbols that you introduce should be defined. Clearly state your assumptions in all problems.

Problem 1: 25 pts.

Problem 2: 25 pts.

Problem 3 25 pts.

Problem 4 25 pts.

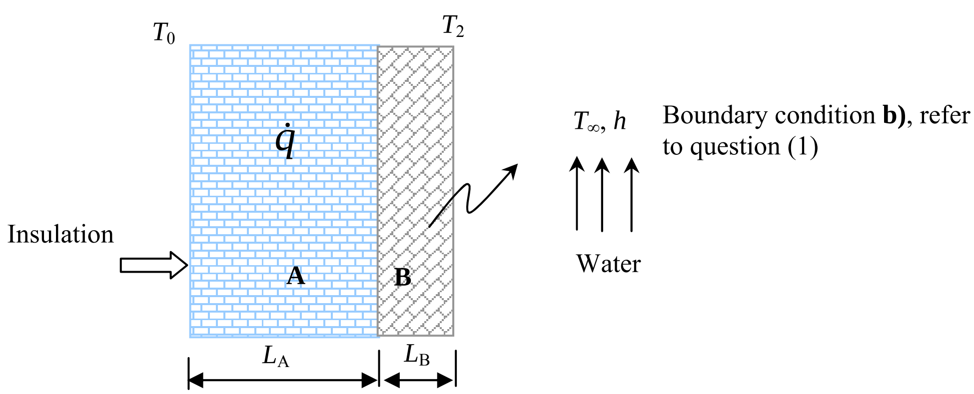
Total Points = 100

1. A plane wall is a composite of two materials, A and B. The wall of material A has uniform heat generation $\dot{q}$. The wall of material B has no heat generation. The inner surface of material A is well insulated. See the figure.

(1) Sketch the temperature distribution in the composite with respect to time when the outer surface of material B is **a)** kept isothermal, **b)** cooled by a water stream with constant temperature T_∞ and heat transfer coefficient h, and **c)** cooled by a constant heat flux.

(2) Determine the temperature T_0 of the insulated surface and the temperature T_2 of the cooled surface under the steady-state condition b) as described in (1).

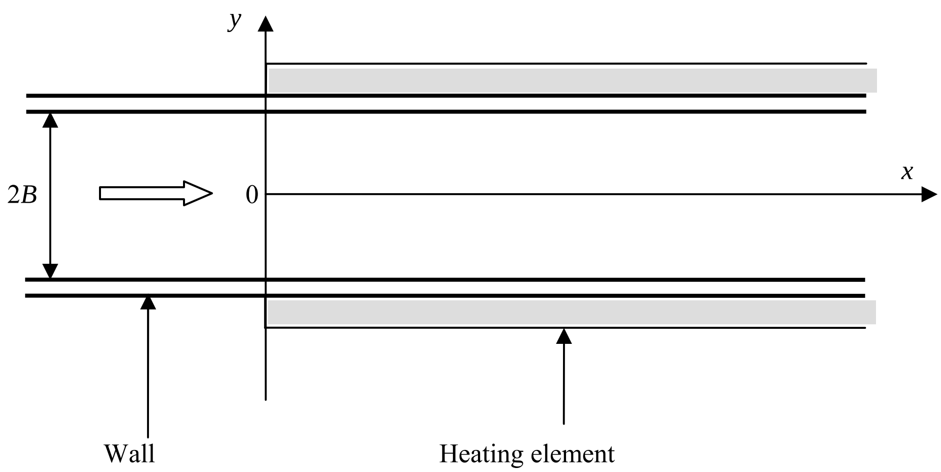
Known conditions: $\dot{q} = 1.5\times10^6\ \text{W/m}^3$, T_∞ = 30 °C, h = 1000 W/m^{2}K, material A of thermal conductivity k_A = 75 W/mK is L_A = 50 mm thick, material B of thermal conductivity k_B = 150 W/mK is L_B = 20 mm thick.



2. Very thick slurries and pastes sometimes move in channels almost as a solid plug. Thus, one can approximate the velocity by a constant value *V* over the conduit cross section.

A viscous fluid with temperature independent physical properties is in fully developed, steady, laminar flow between two flat surfaces placed at a distance 2*B* apart. Viscous dissipation is neglected.

For $x < 0$ the fluid temperature is uniform at $T = T_0$. For $x \geq 0$ heat is added at a constant, uniform flux q''_w at both walls.



1. The energy equation governing the heat diffusion within the slit reads:

$$\rho c_p \left(\frac{\partial T}{\partial t} + v_x \frac{\partial T}{\partial x} + v_y \frac{\partial T}{\partial y} + v_z \frac{\partial T}{\partial z} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$$

Write the simplified form of this equation by taking into account the conditions and assumptions given in the statement of the problem.

2. The simplified energy equation that you have obtained in the first question is a partial differential equation in $T(x, y)$ that requires boundary conditions. Write these boundary conditions at $x = 0$, $y = 0$, and $y = B$.

3. Make the simplified energy equation and its boundary conditions dimensionless by defining the following dimensionless variables:

$$\xi \triangleq \frac{x}{L_x} \qquad \eta \triangleq \frac{y}{L_y} \qquad \Theta \triangleq \frac{T - T_0}{\theta}$$

4. Choose the appropriate scale L_y, θ, and L_x (Hint: Consider the boundary condition at the wall to determine θ, and the energy equation to determine L_x). Then, write the simplified forms of the energy equation and its boundary conditions.

5. Give the criterion to neglect the axial heat diffusion along the duct. Write the energy equation and its boundary conditions when the axial heat diffusion along the duct is neglected.

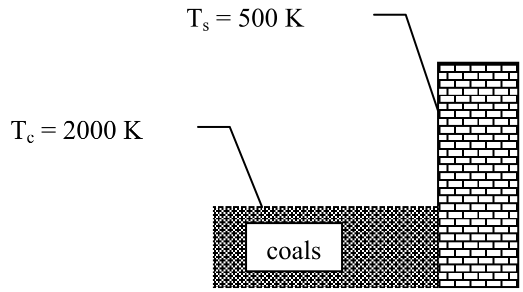
6. Consider a slit with B = 3 mm and a fluid velocity V = 1 cm/s.

    a. If the fluid is sodium at 977 K (thermal diffusivity: 6.12×10^{-5} m^2/s), is the axial heat diffusion along the duct negligible?

    b. If the fluid is glycerin at 320 K (thermal diffusivity: 8.97×10^{-8} m^2/s), is the axial heat diffusion along the duct negligible?

3. A diffuse, fire brick wall of temperature T_s=500 K has the spectral emissivity shown below and is exposed to a bed of coals at a temperature of 2000 K. Determine the total, hemispherical emissivity of the brick wall. What is the total adsorptivity of the wall to irradiation resulting from the emission by the coals?

λ (μm)	ε_λ
$\lambda < 1.5$	0.1
$1.5 < \lambda < 10$	0.5
$10 < \lambda$	0.8



4. High temperature steam flows though a stainless steel pipe with inner and outer diameters given as d_i and d_o, respectively. The pipe wrapped with insulation of a thickness t. The pipe is exposed to air in a crossflow over the outer surface with a velocity V. The air temperature is known to be T_{air} and the surroundings temperature is known as T_{surr}. It is desired to know the rate of heat loss per unit meter from the steam. For this case, set up the equations to the fullest extent possible that will need to be solved. Be sure to specify all parameters that will need to be found/evaluated and give their functional form.

ID Number______________

TABLE 12.1 Blackbody Radiation Functions[a]

λT ($\mu m \cdot K$)	$F_{(0 \to \lambda)}$	$I_{\lambda,b}(\lambda, T)/\sigma T^5$ ($\mu m \cdot K \cdot sr)^{-1}$	$\frac{I_{\lambda,b}(\lambda, T)}{I_{\lambda,b}(\lambda_{max}, T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801
9,500	0.903085	0.765338	0.105956

TABLE 12.1 *Continued*

λT ($\mu m \cdot K$)	$F_{(0 \to \lambda)}$	$I_{\lambda,b}(\lambda, T)/\sigma T^5$ ($\mu m \cdot K \cdot sr)^{-1}$	$\frac{I_{\lambda,b}(\lambda, T)}{I_{\lambda,b}(\lambda_{max}, T)}$
10,000	0.914199	0.653279×10^{-5}	0.090442
10,500	0.923710	0.560522	0.077600
11,000	0.931890	0.483321	0.066913
11,500	0.939959	0.418725	0.057970
12,000	0.945098	0.364394×10^{-5}	0.050448
13,000	0.955139	0.279457	0.038689
14,000	0.962898	0.217641	0.030131
15,000	0.969981	0.171866×10^{-5}	0.023794
16,000	0.973814	0.137429	0.019026
18,000	0.980860	0.908240×10^{-6}	0.012574
20,000	0.985602	0.623310	0.008629
25,000	0.992215	0.276474	0.003828
30,000	0.995340	0.140469×10^{-6}	0.001945
40,000	0.997967	0.473891×10^{-7}	0.000656
50,000	0.998953	0.201605	0.000279
75,000	0.999713	0.418597×10^{-8}	0.000058
100,000	0.999905	0.135752	0.000019

[a] The radiation constants used to generate these blackbody functions are:
$C_1 = 3.7420 \times 10^8$ W $\cdot$ $\mu m^4/m^2$
$C_2 = 1.4388 \times 10^4$ $\mu m \cdot K$
$\sigma = 5.670 \times 10^{-8}$ W/m$^2 \cdot$ K^4.