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國立清華大學 108 學年度碩士班考試入學試題

系所班組別：**工程與系統科學系 乙組**

考試科目(代碼)：**熱傳學(3104)**

—作答注意事項—

1. 請核對答案卷（卡）上之准考證號、科目名稱是否正確。
2. 作答中如有發現試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
3. 考生限在答案卷上標記「↓由此開始作答」區內作答，且不可書寫姓名、准考證號或與作答無關之其他文字或符號。
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6. 其他應考規則、違規處理及扣分方式，請自行詳閱准考證明上「**國立清華大學試場規則及違規處理辦法**」，無法因本試題封面作答注意事項中未列明而稱未知悉。

國立清華大學 108 學年度碩士班考試入學試題

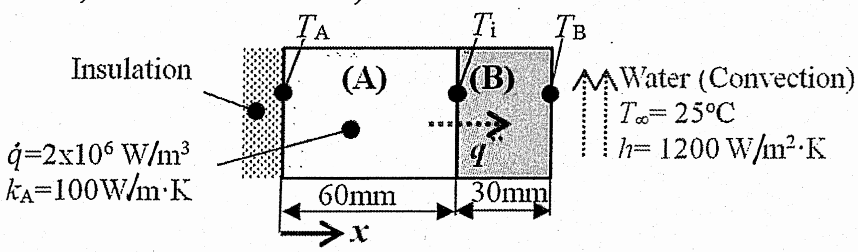
系所班組別：工程與系統科學系碩士班 乙組(0531)

考試科目（代碼）：熱傳學 (3104)

　　*請在【答案卷】作答

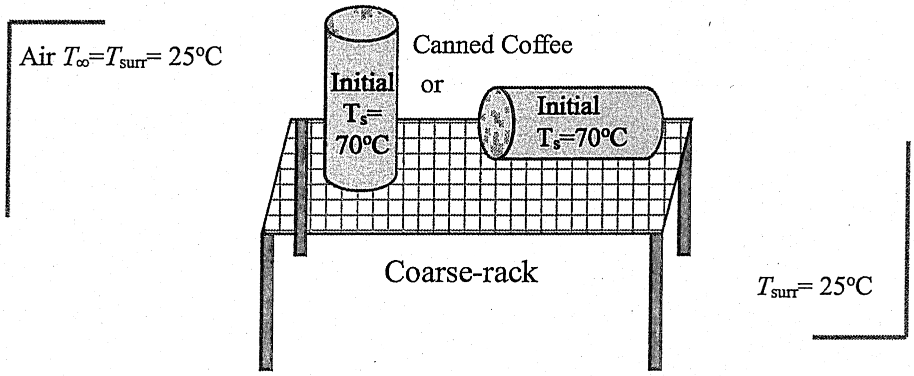
1. **(a)** Several fundamental laws are used to describe the heat transfer relations under various conditions. Please express the equations, briefly explain each term/parameter (including units) and indicate how they are used to calculate the heat transfer rate for the following laws: (a1) Newton's law of cooling **(3%)**, (a2) Fourier's law **(3%)** and (a3) Stefan-Boltzmann's law **(4%)**.
   (b) Define and briefly explain the physical meanings of following dimensionless parameters: (b1) Nusselt number (*Nu*), (b2) Biot number (*Bi*), (b3) Prandtl number (*Pr*), (b4) Grashof number (*Gr*) and (b5) Rayleigh number (*Ra*). **(10%)**

2. **(a)** Considering the energy balance for an infinitesimal control volume in a solid, derive the "Heat Diffusion Equation" in rectangular coordinate (for 3-D, including heat generation and storage terms). **(10%)**
   (b) A long plane wall is a composite of two materials: A and B. The wall of material A has uniform heat generation $\dot{q}$=2x10^6 W/m^3, k_A=100W/m·K and thickness L_B=60mm. The wall of material B has no generation with k_B=200 W/m·K and thickness L_B=30mm. The left surface of material A is well insulated, while the right surface of material B is cooled by a water stream with T_∞= 25°C and h= 1200 W/m^2·K. (b1) Determine the temperatures, T_A **(3%)**, T_i **(2%)** and T_B **(2%)** under steady state conditions. (b2) Sketch the temperature distribution of this composite and outside fluid along x-axis under steady state conditions. **(3%)** (Assume: 1-D, no thermal radiation)



3. **(a)** A spherical thermocouple junction is used for temperature measurement in a gas stream. The heat transfer coefficient between the junction sphere and gas stream is h=500W/m^2·K, and the sphere has properties of ρ=8000 kg/m^3, c=500J/kg·K and k =50W/m·K. (a1) Determine the Biot number and check if this case can be approximated with lumped capacitance method. **(2%)** (a2) Determine the junction diameter needed for the sphere to have a thermal time constant of 1s. **(4%)** (a3) If the junction sphere is initially at 20°C and then placed in the gas stream of 250°C, how long will it take for the junction sphere to reach 249°C? **(4%)** (Assume: no thermal radiation)
   (b) Consider a 75mm-diameter metal sphere (ρ=3000kg/m^3 , c=800J/kg·K, k=150W/m·K) and a gas flow at a temperature of $T_{g,i}$=250°C passing through it. If the initial temperature of the spheres is T_i=20°C and the convection coefficient is h=200W/m^2·K, how long does it take for the sphere to accumulate 90% of the maximum possible thermal energy? What is the corresponding temperature at the center of the sphere? **(10%)** (Assume: no thermal radiation)

4. A cylindrical "canned coffee" (罐裝咖啡) stored in a 70°C hot chamber for a long time has just been taken out and put in a 25°C environments. This coffee can may be put vertically and horizontally on a coarse-rack. Assume air can flow through the coarse-rack freely in any direction without significant frictional loss or change of flow fields, and the rack is made of thin non-conducting material (assume no conduction between can and rack). Please estimate the initial heat dissipation rate (q_{out}) from the coffee can for both conditions. The diameter and the height of the can are 45mm and 90mm, respectively. (Let radiation h_r = 5.6W/m^{2}K or use emissivity ε =0.8, Stefan-Boltzmann's constant σ= 5.67x10^{-8} W/ m^{2}K^4) **(20%)**



5. Consider a concentric tube heat exchanger with an interface area of 80 m^2 operating under the following conditions: (Hint: use LMTD method)

Parameters	Hot-side fluid	Cold-side fluid
Heat capacity rate (kW/K)	8	4
Inlet Temperature, T_{in} (°C)	80	20
Outlet Temperature, T_{out} (°C)	-	76

(a) Determine the outlet temperature of the hot-side fluid. **(5%)**
(b) Is the heat exchanger operating in counter-flow or parallel-flow, or can't you tell from the available information? **(5%)**
(c) Calculate the overall heat transfer coefficient. **(5%)**
(d) Calculate the effectiveness of this heat exchanger. **(5%)**

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<u>Appendix:</u> Some useful equations and tables for the problems.

$$\frac{\theta}{\theta_i}=\frac{T-T_\infty}{T_i-T_\infty}=\exp\left[-\left(\frac{hA_s}{\rho Vc}\right)t\right], \qquad \tau_t=\left(\frac{1}{hA_s}\right)(\rho Vc)=R_tC_t$$

For sphere,

$$\frac{Q}{Q_o}=1-\frac{3\theta_o^*}{\zeta_1^3}\left[\sin(\zeta_1)-\zeta_1\cos(\zeta_1)\right]$$

Equations for one-term approximation (sphere):

$$\theta^*=C_1\exp(-\zeta_1^2Fo)\frac{1}{\zeta_1 r^*}\sin(\zeta_1 r^*)$$

or

$$\theta^*=\theta_o^*\frac{1}{\zeta_1 r^*}\sin(\zeta_1 r^*)$$

Table A1: Coefficients used in one-term approximation to the solutions for transient 1-D conduction

	Plane Wall		Infinite Cylinder		Sphere	
Bi	ζ_1 (rad)	C_1	ζ_1 (rad)	C_1	ζ_1 (rad)	C_1
0.01	0.0998	1.0017	0.1412	1.0025	0.1730	1.0030
0.02	0.1410	1.0033	0.1995	1.0050	0.2445	1.0060
0.03	0.1723	1.0049	0.2440	1.0075	0.2991	1.0090
0.04	0.1987	1.0066	0.2814	1.0099	0.3450	1.0120
0.05	0.2218	1.0082	0.3143	1.0124	0.3854	1.0149
0.06	0.2425	1.0098	0.3438	1.0148	0.4217	1.0179
0.07	0.2615	1.0114	0.3709	1.0173	0.4551	1.0209
0.08	0.2791	1.0130	0.3960	1.0197	0.4860	1.0239
0.09	0.2956	1.0145	0.4195	1.0222	0.5150	1.0268
0.10	0.3111	1.0161	0.4417	1.0246	0.5423	1.0298
0.15	0.3779	1.0237	0.5376	1.0365	0.6609	1.0445
0.20	0.4328	1.0311	0.6170	1.0483	0.7593	1.0592
0.25	0.4801	1.0382	0.6856	1.0598	0.8447	1.0737
0.30	0.5218	1.0450	0.7465	1.0712	0.9208	1.0880
0.4	0.5932	1.0580	0.8516	1.0932	1.0528	1.1164
0.5	0.6533	1.0701	0.9408	1.1143	1.1656	1.1441
0.6	0.7051	1.0814	1.0184	1.1345	1.2644	1.1713
0.7	0.7506	1.0919	1.0873	1.1539	1.3525	1.1978
0.8	0.7910	1.1016	1.1490	1.1724	1.4320	1.2236
0.9	0.8274	1.1107	1.2048	1.1902	1.5044	1.2488
1.0	0.8603	1.1191	1.2558	1.2071	1.5708	1.2732
2.0	1.0769	1.1785	1.5994	1.3384	2.0288	1.4793
3.0	1.1925	1.2102	1.7887	1.4191	2.2889	1.6227
4.0	1.2646	1.2287	1.9081	1.4698	2.4556	1.7202
5.0	1.3138	1.2402	1.9898	1.5029	2.5704	1.7870
6.0	1.3496	1.2479	2.0490	1.5253	2.6537	1.8338
7.0	1.3766	1.2532	2.0937	1.5411	2.7165	1.8673
8.0	1.3978	1.2570	2.1286	1.5526	1.7654	1.8920
9.0	1.4149	1.2598	2.1566	1.5611	2.8044	1.9106
10.0	1.4289	1.2620	2.1795	1.5677	2.8363	1.9249
20.0	1.4961	1.2699	2.2881	1.5919	2.9857	1.9781
30.0	1.5202	1.2717	2.3261	1.5973	3.0372	1.9898
40.0	1.5325	1.2723	2.3455	1.5993	3.0632	1.9942
50.0	1.5400	1.2727	2.3572	1.6002	3.0788	1.9962
100.0	1.5552	1.2731	2.3809	1.6015	3.1102	1.9990
∞	1.5708	1.2733	2.4050	1.6018	3.1415	2.0000

For Natural Convection:

Churchill and Chu's correlation for vertical plate:

$$\overline{Nu}_L = \left\{0.825 + \frac{0.387 Ra_L^{1/6}}{[1 + (0.492/Pr)^{9/16}]^{8/27}}\right\}^2$$

Churchill and Chu's correlation for long horizontal cylinder:

$$\overline{Nu}_D = \left\{0.60 + \frac{0.387\, Ra_D^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2 \qquad Ra_D \lesssim 10^{12}$$

Upper Surface of Hot Plate or Lower Surface of Cold Plate:

$$\overline{Nu}_L = 0.54 Ra_L^{1/4} \quad (10^4 \lesssim Ra_L \lesssim 10^7)$$

$$\overline{Nu}_L = 0.15 Ra_L^{1/3} \quad (10^7 \lesssim Ra_L \lesssim 10^{11})$$

Lower Surface of Hot Plate or Upper Surface of Cold Plate:

$$\overline{Nu}_L = 0.27 Ra_L^{1/4} \quad (10^5 \lesssim Ra_L \lesssim 10^{10})$$

Table A2. Properties of gases at atmospheric pressure

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683