注意：考試開始鈴響前，不得翻閱試題，
並不得書寫、畫記、作答。

國立清華大學 109 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

科目代碼：3104

考試科目：熱傳學

—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。
4. 答案卷用盡不得要求加頁。
5. 答案卷可用任何書寫工具作答，惟為方便閱卷辨識，請儘量使用藍色或黑色書寫；答案卡限用 2B 鉛筆畫記；如畫記不清（含未依範例畫記）致光學閱讀機無法辨識答案者，其後果一律由考生自行負責。
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 109 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)

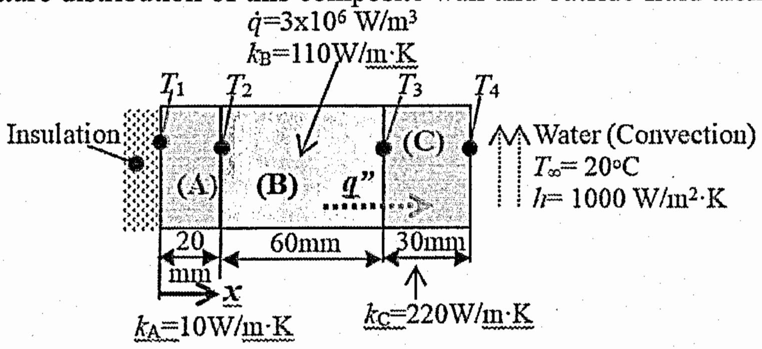
 *請在【答案卷】作答

1. (a) Briefly explain the following heat transfer phenomena, media, corresponding laws and applicable equations: (i) heat conduction **(3%)**, (ii) heat convection **(3%)** and (iii) thermal radiation **(4%)** (also define each parameter including units).

   (b) Express the relations, define each term (including units) and illustrate the physical meanings for the following dimensionless parameters: (i) Nusselt number (Nu) **(4%)**, (ii) Grashof number (Gr) **(3%)** and (iii) Pellet number (Pe) **(3%)**.

2. Derive the "Heat Diffusion Equation" in a rectangular coordinate from energy balance of an infinite small control volume (considering 3-D, transient with heat generation and storage terms) **(10%)**.

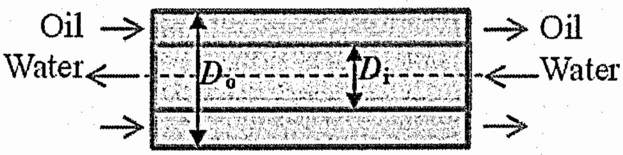
3. A long plane wall is a composite of three materials: A, B and C. The wall material A has no generation with k_A=10 W/m·K and thickness L_A=20mm. The wall of material B has uniform heat generation $\dot{q}$=3x10^6 W/m^3, k_B=110W/m·K and thickness L_B=60mm. The material C has no generation with k_C=220 W/m·K and thickness L_C=30mm. The left surface of material A is well insulated, while the right surface of material C is cooled by a water stream with T_∞= 20°C and h_{avg} = 1000 W/m^2·K. Assume 1-D, no thermal radiation, and steady state conditions. (a) Determine the temperatures T_1 **(4%)**, T_2 **(4%)** and T_3 **(4%)** and T_4 **(4%)**. (b) Sketch the temperature distribution of this composite wall and outside fluid along the x-axis. **(6%)**



4. (a) The log mean temperature difference (LMTD) method is commonly used in heat exchanger analysis. Please express the log mean temperature difference (ΔT_{lm}) for "counter-flow" and "parallel-flow" heat exchangers, respectively, and indicate which ΔT_{lm} could be larger if both heat exchangers have the same hot-/cold-side inlet/outlet temperatures? **(5%)** (You can assume the parameters if needed.)

(b) A counter-flow concentric-tube heat exchanger is used to cool the lubrication oil of an industrial engine. The cooling water is flowing through the inner circular tube with a diameter of 25mm (D_i); while the oil is flowing through the outer annulus with an outer diameter of 50mm (D_o). Detailed fluid/flow parameters have been listed in the following table. The averaged inlet temperatures of oil and water are 95°c and 30°C, respectively. If the required outlet temperature of oil is 55°C, please determine the following parameters: (i) outlet temperature of water flow **(3%)**, (ii) the log mean temperature difference **(4%)**, (iii) overall heat transfer coefficient **(4%)**, (iv) the length of this heat exchanger **(4%)** and (v) the effectiveness of this heat exchanger **(4%)**? (Assume no heat loss from this heat exchanger, and the wall thickness can be ignored.)

Parameters	Oil	Water	Parameters	Oil	Water
Heat capacity, C_p (J/kg·K)	2131	4178	Thermal conductivity, k (W/m·K)	0.138	0.625
Mass flow rate, $\dot{m}$ (kg/s)	0.2	0.4	Dynamic viscosity, μ (N·s/m^2)	3.25×10^{-2}	725×10^{-6}
Inlet temperature, T_{in} (°C)	95	30	Prandtl number, Pr (-)	501	4.85
Outlet temperature, T_{out} (°C)	55	?	-	-	-



5. A horizontal thin-walled circular tube with a diameter of 6 mm and length of 20 m is used to carry exhaust gas from a smoke oven to a process chamber. The exhaust gas enters the tube at 200°C with a mass flow rate of 0.003 kg/s. Mild winds at a temperature of 15 °C blow directly across the tube at a velocity of 5 m/s. (Assume: exhaust gas properties are those of air, steady state, ignore thermal radiation)

(a) Estimate the average heat transfer coefficient for the exhaust gas flowing inside the tube. **(5%)**

(b) Estimate the heat transfer coefficient for the outside air flowing across the tube. **(5%)**

(c) Estimate the overall heat transfer coefficient (U) and the temperature of the exhaust gas when it reaches the process chamber. **(6%)**

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(d) If the wind velocity is about zero (assume natural convection), estimate the overall heat transfer coefficient (U) and the exhaust gas temperature when it reaches the process chamber. **(8%)**

Appendix: Some useful equations and tables for the problems.

TABLE 1 Nusselt number for fully developed laminar flow in a circular tube annulus with one surface insulated and the other at constant temperature

D_i/D_o	Nu_i	Nu_o	*Comments*
0	—	3.66	See Equation 8.55
0.05	17.46	4.06	
0.10	11.56	4.11	
0.25	7.37	4.23	
0.50	5.74	4.43	
≈1.00	4.86	4.86	See Table 8.1, $b/a \rightarrow \infty$

Adapted from Lundberg, R.E., W.C. Reynolds, and W.M. Kays, *Heat Transfer with Laminar Flow in Concentric Annuli with Constant and Variable Wall Temperature and Heat Flux*, NASA TN D-1972, 1963.

Correlation for non-circular cylinder in a cross-flow:

$$\overline{Nu}_D \equiv \frac{\bar{h}D}{k} = C\,Re_D^m\,Pr^{1/3} \quad \text{(a1)}$$

Correlation for circular cylinder in a cross-flow:

$$\overline{Nu}_D = C\,Re_D^m\,Pr^n\left(\frac{Pr}{Pr_s}\right)^{1/4} \quad \text{(a2)}$$

$$\begin{bmatrix} 0.7 \lesssim Pr \lesssim 500 \\ 1 \lesssim Re_D \lesssim 10^6 \end{bmatrix}$$

if $Pr \gtrsim 10$, $n = 0.36$
$Pr \lesssim 10$, $n = 0.37$;

TABLE 2 Constants of Equation (a1) for noncircular cylinders in cross flow of a gas [13]

Geometry	Re_D	C	m
Square			
$V \rightarrow$ (diamond, D)	5×10^3–10^5	0.246	0.588
$V \rightarrow$ (square, D)	5×10^3–10^5	0.102	0.675
Hexagon			
$V \rightarrow$ (hexagon, D)	5×10^3–1.95×10^4	0.160	0.638
	1.95×10^4–10^5	0.0385	0.782
$V \rightarrow$ (hexagon, D)	5×10^3–10^5	0.153	0.638
Vertical plate			
$V \rightarrow$ (D)	4×10^3–1.5×10^4	0.228	0.731

TABLE 3 Constants of Equation (a2) for the circular cylinder in cross flow [17]

Re_D	C	m
1–40	0.75	0.4
40–1000	0.51	0.5
10^3–2×10^5	0.26	0.6
2×10^5–10^6	0.076	0.7

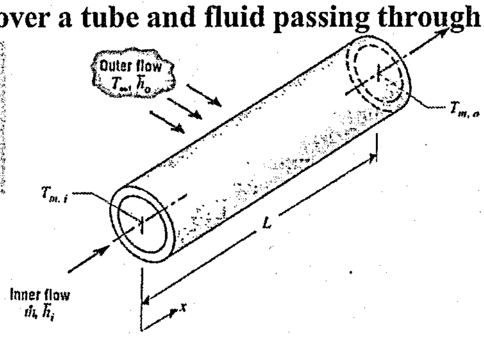
Dittus-Boelter equation
for turbulent flow in circular pipes: $Nu_D = 0.023 Re_D^{4/5} Pr^n$ $\begin{bmatrix} 0.6 \lesssim Pr \lesssim 160 \\ Re_D \gtrsim 10{,}000 \\ \frac{L}{D} \gtrsim 10 \end{bmatrix}$

$n = 0.4$ for heating ($T_s > T_m$) and 0.3 for cooling ($T_s < T_m$).

Heat Transfer between fluid flowing over a tube and fluid passing through the tube:

$$\frac{\Delta T_o}{\Delta T_i} = \frac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \exp\left(-\frac{\overline{U}A_s}{\dot{m}c_p}\right)$$

$$q = \overline{U}A_s \Delta T_{lm}$$



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 4 Thermophysical Properties of Gases at Atmospheric Pressure[a]

T (K)	ρ (kg/m³)	c_p (kJ/kg·K)	$\mu \cdot 10^7$ (N·s/m²)	$\nu \cdot 10^6$ (m²/s)	$k \cdot 10^3$ (W/m·K)	$\alpha \cdot 10^6$ (m²/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
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709