國立中山大學113學年度
碩士班暨碩士在職專班招生考試試題

科目名稱：基礎熱傳學【機電系碩士班甲組】

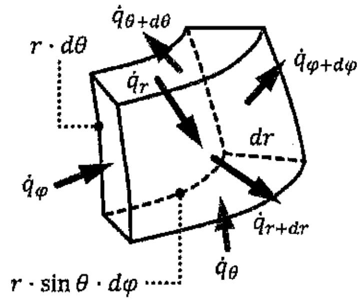
—作答注意事項—

考試時間：100分鐘

- **考試開始鈴響前不得翻閱試題，並不得書寫、劃記、作答。**請先檢查答案卷（卡）之應考證號碼、桌角號碼、應試科目是否正確，如有不同立即請監試人員處理。
- **答案卷限用藍、黑色筆(含鉛筆)書寫、繪圖或標示**，可攜帶橡皮擦、無色透明無文字墊板、尺規、修正液（帶）、手錶(未附計算器者)。每人每節限使用一份答案卷，請衡酌作答。
- 答案卡請以2B鉛筆劃記，不可使用修正液（帶）塗改，未使用2B鉛筆、劃記太輕或污損致光學閱讀機無法辨識答案者，後果由考生自負。
- 答案卷（卡）應保持清潔完整，不得折疊、破壞或塗改應考證號碼及條碼，亦不得書寫考生姓名、應考證號碼或與答案無關之任何文字或符號。
- 可否使用計算機請依試題資訊內標註為準，如「可以」使用，廠牌、功能不拘，唯不得攜帶書籍、紙張（應考證不得做計算紙書寫）、具有通訊、記憶、傳輸或收發等功能之相關電子產品或其他有礙試場安寧、考試公平之各類器材入場。
- **試題及答案卷（卡）請務必繳回，未繳回者該科成績以零分計算。**
- **試題採雙面列印，考生應注意試題頁數確實作答。**
- **違規者依本校招生考試試場規則及違規處理辦法處理。**

Question 1 **(10 points)**

Given a differential element cut out of a spherical shell. Starting with an energy balance, as well as the Fourier's Law, derive the heat diffusion equation in spherical coordinate system. Assume isotropic and homogeneous medium and a constant volumetric internal heat generation rate be $\dot{q}_g'''$.



Question 2 **(30 points)**

Consider a thin rectangular plate in the domain $\{(x,y)\mid 0 \le x \le \alpha\,;\, 0 \le y \le \beta\}$. The top edge at $y=\beta$ is subjected to a constant heat flux $\dot{q}_s''$. The temperatures at all other edges are kept constant at T_0.

a) Write down the governing partial differential equation for steady-state conduction in the slab with the associated boundary conditions. (6 points)

b) Let $\theta^* = \dfrac{T - T_0}{\dfrac{\dot{q}_s'' \cdot \alpha}{k}}$, $x^* = \dfrac{x}{\alpha}$, $y^* = \dfrac{y}{\alpha}$. Rewrite the governing equation and the boundary conditions in *part a)* in non-dimensional form. Must show all steps for points. (8 points)

c) Prove that, the series expansion solution to the steady state temperature distribution is given by,

$$\theta(x,y) = \sum_{n=1}^{\infty} C_n \cdot \sin(n \cdot \pi \cdot x) \cdot \sinh(n \cdot \pi \cdot x),$$

where C_n is given by, $C_n = -2 \cdot \left[\dfrac{1-(-1)^n}{(n\cdot\pi)^2 \cdot \cosh\left(n \cdot \pi \cdot \dfrac{\beta}{\alpha}\right)} \right]$. (16 points)

Question 3 **(30 points)**

A cylinder of diameter 0.025 m and length of 0.2 m, with an opaque and diffuse surface, is placed in a fan-assisted oven. The walls of the oven are at 1000 K. The cylinder is exposed to quiescent hot air at 750 K in the oven. The surface emissivity of the cylinder is given as,

$$\varepsilon_\lambda = \begin{cases} \varepsilon_1 = 0.8 & 0 \le \lambda < 4\ \mu\text{m} \\ \varepsilon_2 = 0.2 & 4\ \mu\text{m} \le \lambda \le \infty \end{cases}.$$

Assume the initial temperature of the cylinder be 300 K.

a) Find the initial total, hemispherical emissivity, and absorptivity of the cylinder. (9 points)

b) Calculate the convective heat transfer coefficient of the cylinder surface initially. (6 points)

c) Evaluate the net rate of heat transfer initially. (6 points)

d) Determine the steady-state temperature on the cylinder surface. Evaluate air properties at the film temperature of 862.5 K. (9 points)

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※本科目依簡章規定「可以」使用計算機（廠牌、功能不拘）（問答申論題）　　共4頁第2頁

Question 4 **(10 points)**

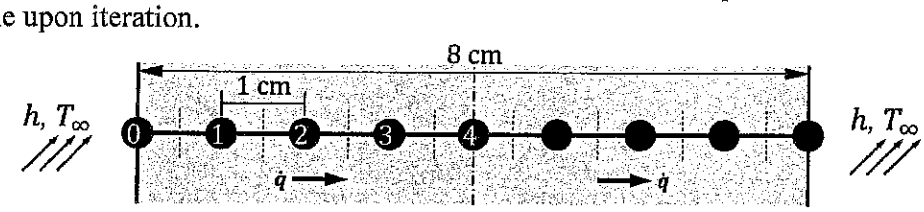
Given a brand new concentric tube heat exchanger with smooth walls, the outer cylinder has a diameter of 0.04 m and inner cylinder with diameter of 0.03 m. The length of the heat exchanger is 9 m. Air is flowing in the space between the inner and outer tubes with mass flow rate of 0.05 kg/s and enters the heat exchanger at temperature of 245 K and pressure of 1 MPa. Condensing steam is flowing in the inner tube at 110 kPa. Assume the heat exchanger assembly is perfectly insulated.

a) Find the averaged heat transfer coefficient. (7 points)
b) Calculate the outlet temperature of the air stream. (3 points)

Question 5 **(10 points)**

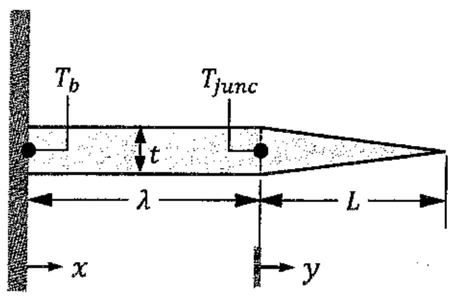
Consider a thick slab of soda lime glass with thickness of 8 cm, initially at 573 K. It is subject to cooling by air at 303 K, blowing across its surface with a velocity of 25 m/s. Assume the slab of glass is 2 m long. For properties evaluation, assume the surface temperature of the glass be 317 K.

a) Derive the transient finite difference equations for nodes 0 to 4, using an explicit scheme. (3 points)
b) Determine the largest possible time-step sizes such that the explicit scheme will not become unstable upon iteration. (7 points)



Question 6 **(10 points)**

Fins are being installed outside a chimney with the surface temperature at T_b. The fin consists a rectangular portion, which is protruding with a length of λ from the chimney wall. It has another fin with triangular cross-section that further extends for another length of L from the end of the rectangular fin. The fin surface is subjected to convective cooling by air at T_∞ and the heat transfer coefficient is estimated as h and its thermal conductivity to be k. Assume the width to be W.



a) Prove that the temperature distribution and heat transfer rate in the rectangular portion are given by,

$$T(x) = T_\infty + (T_\lambda - T_\infty)\cdot\frac{\sinh(\beta\cdot x)}{\sinh(\beta\cdot\lambda)} + (T_b - T_\infty)\cdot\frac{\sinh(\beta\cdot(\lambda - x))}{\sinh(\beta\cdot\lambda)}$$

and $$\dot{q}(x) = -k\cdot(t\cdot W)\cdot\beta\cdot\left[(T_\lambda - T_e)\cdot\frac{\cosh(\beta\cdot x)}{\sinh(\beta\cdot\lambda)} + (T_b - T_e)\cdot\frac{\cosh(\beta\cdot(\lambda - x))}{\sinh(\beta\cdot\lambda)}\right].$$

where $\beta^2 = \frac{2\cdot h}{k\cdot t}$ and $T_\lambda = T(x=\lambda)$. (6 points)

b) Prove that the temperature at the junction, $T_{junc} = T_\lambda$, is given by,

$$T_{junc} = \frac{T_b}{\sinh(\beta\cdot\lambda)\cdot\eta_{fin}\cdot\beta\cdot L + \cosh(\beta\cdot\lambda)},$$

where η_{fin} is the fin efficiency. (4 points)

試題請隨卷繳回，請留意背面是否有題

Appendix

Selected material properties

Property	Material	Temperature	Value
Density, ρ	Water		1000 kg/m^3
	Air	268.5 K (1 atm)	1.2 kg/m^3
	Air	310 K (1 MPa)	11.41 kg/m^3
	Air	356.5 K (1 atm)	0.9902 kg/m^3
Viscosity, v	Water		1.5×10^{-6} m^2/s
	Air	268.5 K	1.298×10^{-5} m^2/s
	Air	310 K	1.654×10^{-5} m^2/s
	Air	356.5 K	2.131×10^{-5} m^2/s
	Air	525 K	4.114×10^{-5} m^2/s
	Air	862.5 K	9.326×10^{-5} m^2/s
Thermal Diffusivity, α	Air	268.5 K	1.765×10^{-5} m^2/s
Prandtl Number, Pr	Air	268.5 K	0.7355
	Air	310 K	0.7252
	Air	356.5 K	0.7151
	Air	525 K	0.6953
	Air	862.5 K	0.7031
Specific Heat, C_p	Water		4200 J/kg·K
	Air		1005 J/kg·K
Saturation Temperature, T_{sat}	Water	**at 110 kPa**	375.3 K
Thermal Conductivity, k	Water		0.6 W/m·K
	Air	268.5 K	0.02328 W/m·K
	Air	310 K	0.02740 W/m·K
	Air	356.5 K	0.02977 W/m·K
	Air	525 K	0.04116 W/m·K
	Air	862.5 K	0.06039 W/m·K

Correlations for Nusselt Numbers

- Cylinder with external cross flow:

$$\overline{Nu}_D = 0.3 + \frac{0.62 \cdot Re_D^{1/2} \cdot Pr^{1/3}}{\left[1+\left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \cdot \left[1+\left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$$

- Fully developed laminar flow with uniform surface temperature: $\overline{Nu}_D = 3.66$

- Fully developed laminar flow with uniform surface heat flux: $\overline{Nu}_D = 4.36$

- Mixed boundary layer over a flat plate,

$$\overline{Nu}_L = \left[0.037 \cdot Re_L^{4/5} - 871\right] \cdot Pr^{1/3} \qquad \text{for} \qquad Ra_D \le 10^{12}$$

- Long, horizontal cylinder in quiescent ambient,

$$\overline{Nu}_D = \left\{ 0.6 + \frac{0.387 \cdot Ra_D^{1/6}}{\left[1 + \left(\frac{0.559}{Pr}\right)^{9/16}\right]^{8/27}} \right\}^2 \quad \text{for} \quad Ra_D \le 10^{12}.$$

- Fully developed turbulent flow,

$$\overline{Nu}_D = \frac{\frac{f}{8} \cdot (Re_D - 1000) \cdot Pr}{1 + 12.7 \cdot \left(\frac{f}{8}\right)^{1/2} \cdot \left(Pr^{2/3} - 1\right)}$$

  - where the friction factor, f, is given by,

$$\frac{1}{\sqrt{f}} = \begin{cases} -2.0 \cdot \log\left(\frac{\varepsilon / D}{3.7} + \frac{2.51}{Re_D \cdot \sqrt{f}}\right) & \text{for rough wall} \\ 0.790 \cdot \ln(Re_D) - 1.64 & \text{for smooth wall} \end{cases}$$

Heat Exchangers Effectiveness Correlations

- Parallel Flow:

$$\varepsilon = \frac{1 - \exp\left[-NTU \cdot (1 + C_r)\right]}{1 + C_r}$$

- Counter Flow:

$$\varepsilon = \frac{1 - \exp\left[-NTU \cdot (1 - C_r)\right]}{1 - C_r \cdot \exp\left[-NTU \cdot (1 - C_r)\right]} \quad \text{for} \quad C_r < 1$$

$$\varepsilon = \frac{NTU}{1 + NTU} \quad \text{for} \quad C_r = 1$$

Heat Exchangers NTU Correlations

- Parallel Flow:

$$NTU = -\frac{\ln\left[1 - \varepsilon \cdot (1 + C_r)\right]}{1 + C_r}$$

- Counter Flow:

$$NTU = \frac{1}{C_r - 1} \cdot \ln\left(\frac{\varepsilon - 1}{\varepsilon \cdot C_r - 1}\right) \quad \text{for} \quad C_r < 1$$

$$NTU = \frac{\varepsilon}{1 - \varepsilon} \quad \text{for} \quad C_r = 1$$