UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2012/2013 Academic Session

June 2013

EKC 216 – Process Heat Transfer
[Pemindahan Haba Proses]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SIX printed pages and THREE printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan TIGA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Consider a copper pin fin [k = 410 W/m.K] of 0.4 cm in diameter that protrudes from a wall at 120 ^oC into ambient air at 20 ^oC. The convection coefficient was equal to 12.0 W/m^2.K. Calculate:

Sebatang sirip pin tembaga [k = 410 W/m.K] berdiameter 0.4 sm terkeluar daripada sebuah dinding bersuhu 120 ^oC. Suhu udara ambien ialah 20 ^oC. Pemalar perolakan haba ialah 12.0 W/m^2.K. Kirakan:

[i] heat loss, assuming that the fin is "infinitely long".
kehilangan haba, dengan menganggap sirip itu "panjang tak terhingga".

[ii] heat loss, assuming that the fin is 4.2 cm long with convecting tip.
kehilangan haba, dengan menganggap sirip itu 4.2 sm panjang dengan hujungnya berperolakan. *[8 marks/markah]*

[b] A wall with a cross sectional area of 4.4 m^2 is constructed with 3.8 cm of concrete (k = 1.4 W/m.K), 3.0 cm of fiberglass insulation (k = 0.04 W/m.K) and 2.0 cm of gypsum board (k = 0.06 W/m.K). The inside and outside convection coefficients are 11.2 and 30.8 W/m^2.K, respectively. The inside temperature is 320 ^oC and interface between fiberglass and gypsum board is 160.5 °C. Calculate:

Sebuah dinding berkeluasan 4.4 m^2 dibina daripada konkrit (k = 1.4 W/m.K), *berketebalan 3.8 sm, penebat gentian kaca (k = 0.04 W/m.K) berketebalan 3.0 sm dan papan gipsum (k = 0.06 W/m.K) berketebalan 2.0 sm. Pemalar perolakan dalam dan luar masing-masing ialah 11.2 dan 30.8 W/m^2.K. Suhu udara di dalam ialah 320 ^oC dan suhu di antara permukaan gentian kaca dan papan gipsum ialah 160.5 ^oC. Kirakan:*

[i] heat loss
kehilangan haba

[ii] outside air temperature
suhu udara di luar *[6 marks/markah]*

[c] A fluid at a temperature of 150 ^oC flows through a steel tube (k = 22.6 W/m.K) of 35 m length. The tube has an inside diameter of 2.8 cm and thickness of 2.4 mm. The tube is covered with a 15 mm thick layer of insulation (k = 0.07 W/m.K). The convection coefficients at the inside and outside are 24.8 W/m^2.K and 14.5 W/m^2.K, respectively. The pipe is located in a room at 30^{o}C. Calculate the:

*Suatu bendalir bersuhu 150 ^oC mengalir melalui tiub keluli (*k *= 22.6 W/m.K) 35 m panjang. Tiub ini mempunyai diameter dalaman 2.8 sm dan ketebalan 2.4 mm. Tiub ini diliputi dengan lapisan penebat (*k *= 0.07 W/m.K) berketebalan 15 mm. Pemalar perolakan dalaman dan luaran masing-masing ialah 24.8 W/m^2.K dan 14.5 W/m^2.K. Paip ini terletak di dalam bilik bersuhu 30 ^oC. Kirakan :*

[i] overall heat transfer coefficient based on the outer surface area
pemalar pemindahan haba keseluruhan berdasarkan luas permukaan luar

[ii] heat loss from the pipe
kehilangan haba daripada paip [4 marks/markah]

[d] A truncated cooper (k = 350 W/m.K) cone is 50 cm in height. The diameter at the top is 5.2 cm and the diameter at the bottom is 20.2 cm. The lower surface is maintained at 30 ^oC and the upper surface at 230 ^oC. The outer surface is insulated. Assuming one-dimensional heat flow, what is the rate of heat transfer?

Kon pemepat dengan tinggi 50 sm dibina daripada tembaga (k = 350 W/m.k). Diameter di bahagian atas ialah 5.2 sm dan diameter di bahagian bawah ialah 20.2 sm. Suhu di bahagian bawah dikekalkan pada 30 ^oC dan di sebelah atas pada 230 ^oC. Permukaan luar kon ini ditebat. Anggap aliran haba pada satu dimensi, apakah kadar permindahan haba? [4 marks/markah]

[e] A 10 cm thick plate (k = 34.0 W/m.K) generates heat uniformly at the rate of 8.0 x 10^3 W/m^3. One side of the plate is maintained at 250 ^oC and the other side at 30 ^oC. Calculate the temperature at the center of the plate.

Sebuah plat (k = 34.0 W/m.K) berketebalan 10 sm menghasilkan haba sekata pada kadar 8 x 10^3 W/m^3. Suhu di sebelah permukaan plat dikekalkan pada 250 ^oC manakala di sebelah lain pada 30 ^oC. Kirakan suhu di bahagian tengah plat. [3 marks/markah]

2. [a] Water at the rate of 3.6 kg/s is heated from 25 to 84 ^oC in a 3 cm diameter tube where surface is at 96 ^oC. What is the length (in meter) of the tube needed to accomplish this heating.

Air pada kadar 3.6 kg/s dipanaskan daripada 25 ke 84 ^oC di dalam tiub berdiameter 3 sm di mana suhu permukaannya adalah 96 ^oC. Berapakah panjang tiub (dalam meter) bagi melengkapkan proses pemanasan ini?
[5 marks/markah]

[b] A tube bank consists of 144 tubes arranged in a square inline array. The tubes have a diameter of 1.5 cm and a length of 1 m. The center to center tube spacing is 3 cm. If the surface temperature of the tubes is maintained at 440 K and air enters the tube bank at 1 atm, 360 K, and u_∞ = 8 m/s, calculate the total heat loss by the tubes.

Barisan 144 tiub disusun dengan tatasusunan segiempat sama. Tiub-tiub tersebut mempunyai diameter 1.5 sm dan panjang 1 m. Jarak pusat-ke-pusat tiub ialah 3 sm. Jika suhu permukaan tiub dikekalkan pada 440 K dan udara memasuki barisan tiub pada 1 atm, 360 K dan u_∞ = 8 m/s, kirakan jumlah kehilangan haba keseluruhan dari tiub-tiub tersebut.
[8 marks/markah]

[c] Calculate the free-convection heat loss from a 0.4 m^2 vertical plate maintained at 230 ^oC and exposed to air at 1 atm and 24 ^oC.

Kirakan kadar kehilangan haba secara perolakan bebas dari plat menegak berkeluasan 0.4 m^2 yang dikekalkan pada suhu 230 ^oC dan terdedah kepada udara 1 atm dan 24 ^oC. *[6 marks/markah]*

[d] Two vertical plates 50 by 50 cm are separated by a space of 4 cm that is filled with water. The plates temperature are 110 ^oC and 32 ^oC respectively. Calculate the heat transfer across the space.

Dua plat menegak 50 x *50 sm dipisahkan oleh ruang yang diisi dengan air sejauh 4 sm. Suhu plat ialah pada 110 ^oC dan 32 ^oC. Kirakan pemindahan haba sepanjang ruang tersebut.* *[6 marks/markah]*

3. Two plates of 1.44 m^2 are spaced side by side by 1.2 m distance. The emissivities of the plates are 0.4 and 0.6, and the temperatures are 1033 K and 573 K, respectively. A radiation shield having similar area with an emissivity of 0.05 on both sides is located equidistant between the two plates. The three plates are placed in a large room which is maintained at 313 K.

Dua plat bersaiz 1.44 m^2 dipisahkan sisi dengan sisi sejauh 1.2 m. Keberpancaran plat-plat berkenaan ialah 0.4 dan 0.6 dan suhu masing-masing adalah 1033 K dan 573 K. Suatu perisai radiasi yang mempunyai keluasan yang sama dengan keberpancaran 0.05 pada kedua-dua bahagian diletakkan di tengah-tengah plat-plat tersebut. Ketiga-tiga plat diletakkan di dalam bilik yang besar di mana suhu dikekalkan pada 313 K.

[a] Calculate the wavelength and spectral emissive power (per unit area per unit wavelength) associated with maximum emission to the room. Show your result in a graphical form.

Kirakan panjang gelombang dan kuasa pancaran spektrum (per unit keluasan per unit panjang gelombang) yang bersekutu dengan pemancaran maksimum ke bilik. Tunjukkan keputusan anda dalam bentuk grafik.

<u>Given:</u>
<u>Diberikan:</u>

Wien's displacement constants are 2897.6μmK and 1.28612$Wm^{-2}K^{-5}\mu m\times10^{-11}$, respectively.

Pemalar anjakan Wien ialah masing-masing 2897.6 μmK dan 1.28612 $Wm^{-2}K^{-5}\mu m\times10^{-11}$ *[6 marks/markah]*

[b] Identify the types of radiation (gamma, X-ray, UV, visible, near IR, mid IR, far IR, microwave or radio wave) obtained from result Q.3.[a]. above.

Kenalpastikan jenis radiasi (gama, sinar X, boleh dilihat, IR dekat, IR pertengahan, IR jauh, gelombang mikro atau gelombang radio) yang diperolehi daripada keputusan S.3.[a]. di atas. *[3 marks/markah]*

…5/-

[c] With proper diagrams, calculate the temperature of the shield.
Menggunakan gambarajah yang sesuai, kirakan suhu perisai.

<u>Given:</u>
<u>*Diberi:*</u>

$\sigma = 5.669 \times 10^{-8} Wm^{-2}K^{-4}$
Shape factor = 0.2
Faktor bentuk = 0.2 *[6 marks/markah]*

[d] Calculate the percentage change in heat transfer from the lower temperature plate after the shield is added. Explain the reason.
Kirakan peratus perubahan dalam pemindahan haba daripada plat bersuhu rendah setelah perisai ditambah. Terangkan sebabnya. *[10 marks/markah]*

4. Hot water flowing at 2 kg/s, 368 K enters a heat exchanger shell to heat water flowing cross-current inside the tube side from 308 K to 328 K. The overall heat coefficient of the exchanger is 1420 W/m^2K and specific heat of water is 4182 J/kg.K.

Air panas mengalir pada 2 kg/s, 368 K memasuki kelompang penukar haba untuk memanaskan air yang mengalir secara bersilangan di dalam bahagian tiub daripada 308 K kepada 328 K. Pekali haba keseluruhan bagi penukar tersebut ialah 1420 W/m^2K dan haba tentu bagi air ialah 4182 J/kg.K.

[a] Calculate the exit temperature of the hot water in Kelvin. State your assumption clearly.
Kirakan suhu keluar air panas dalam Kelvin. Nyatakan andaian anda dengan jelas. *[4 marks/markah]*

[b] Calculate the effectiveness of the exchanger.
Kirakan keberkesanan penukar haba tersebut.
[3 marks/markah]

[c] Calculate the length of the tube in meter.
Kirakan panjang tiub dalam meter.
[5 marks/markah]

[d] Calculate the number of 20 mm diameter tubes required if water in the tube side flows at 4 kg/s.

Kirakan bilangan 20 mm garis pusat tiub yang diperlukan sekiranya air di dalam tiub mengalir pada 4 kg/s.

<u>Given:</u>
<u>*Diberi:*</u>

Velocity of water = 0.4 m/s
Kelajuan air = 0.4 m/s

Density of water = 1000 kg/m^3
Ketumpatan air = 1000 kg/m^3 *[4 marks/markah]*

[e] Calculate the new length of the tube if the number of tube passes is 2. The correction factor due to bending is 0.88.

Kirakan panjang baru tiub berkenaan sekiranya bilangan laluan tiub ialah 2. Faktor pembetulan disebabkan lengkukan ialah 0.88. *[4 marks/markah]*

[f] Calculate effectiveness of the exchanger after making 2 tube passes and explain how it can be improved without changing the designed parameters (i.e, flow rate, cooling and heating fluids, number of tube passes and sizing).

Kirakan keberkesanan penukar tersebut selepas membuat 2 laluan tiub dan terangkan bagaimana ia boleh diperbaiki tanpa mengubah parameter rekabentuk (contohnya, kadar aliran, bendalir penyejuk dan pemanas, bilangan laluan tiub dan saiz). *[5 marks/markah]*

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Appendix

For fin; m^2=hP/kA & $M = \sqrt{hPkA}\left(T_b - T_\infty\right)$

For convecting tip fin; $q = M \dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$

For infinite long fin; q = M

$$U_o = \dfrac{1}{\dfrac{r_3}{r_1.h_1} + \dfrac{r_3 \ln\left(r_2/r_1\right)}{k_1} + \dfrac{r_3 \ln\left(r_3/r_2\right)}{k_2} + \dfrac{1}{h_2}}$$

Plane wall with assymmetrical distribution :

$$T_x = \frac{T_{w1} + T_{w2}}{2} + \left(\frac{T_{w1} + T_{w2}}{2}\right)\frac{x}{L} + q'''\frac{L^2}{2k}\left[1 - \frac{x^2}{L^2}\right]$$

For cone; r = ax + b

$$q = hA(T_w - T_b) = mc_p(T_{b2} - T_{b1})$$

$$\mathrm{Re}_d = \frac{\rho u_m d}{\mu} = \frac{\dot{m}\, d}{S\mu}$$

For force convection in tube (Laminar flow) : $Nu_d = 1.86(\mathrm{Re}_d \Pr \frac{d}{L})^{1/3}\left(\dfrac{\mu}{\mu_w}\right)^{0.14}$

For force convection in tube (Tubulent flow) : $Nu_d = 0.023\,\mathrm{Re}_d^{0.8} \Pr^n$

For air flow across wire: $Nu = \dfrac{hd}{k} = C\left(\mathrm{Re}\right)^n \Pr^{1/3}$

For natural convection, Nusselt number : $Nu = C(Gr\ \Pr)^m$

For air, $Gr\Pr = \left(\dfrac{g\beta(T_1 - T_2)\delta^3}{v^2}\right)\Pr$

For water, $\dfrac{k_e}{k} = C(Gr\Pr)^n\left(\dfrac{L}{\delta}\right)^m$ and $q = \dfrac{k_e A(T_1 - T_2)}{\delta}$

Modified correlation of Grimson for heat transfer in tube banks of 10 rows or more

$\frac{S_p}{d}$	$\frac{S_n}{d}$ = 1.25 C	1.25 n	1.5 C	1.5 n	2.0 C	2.0 n	3.0 C	3.0 n
In line								
1.25	0.386	0.592	0.305	0.608	0.111	0.704	0.0703	0.752
1.5	0.407	0.586	0.278	0.620	0.112	0.702	0.0753	0.744
2.0	0.464	0.570	0.332	0.602	0.254	0.632	0.220	0.648
3.0	0.322	0.601	0.396	0.584	0.415	0.581	0.317	0.608

Properties of air at atmospheric pressure†

The values of μ, k, c_p, and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures.

T, K	ρ kg/m^3	c_p, kJ/kg · K	$\mu \times 10^5$, kg/m · s	$\nu \times 10^6$, m^2/s	k, W/m · K	$\alpha \times 10^4$, m^2/s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680

Table I Properties of water (saturated liquid).†

Note: $Gr_x \, Pr = \left(\frac{g\beta\rho^2 c_p}{\mu k}\right) x^3 \Delta T$

°F	°C	c_p kJ/kg · °C	ρ kg/m^3	μ kg/m · s	k W/m · °C	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$ 1/m^3 · °C
32	0	4.225	999.8	1.79×10^{-3}	0.566	13.25	
40	4.44	4.208	999.8	1.55	0.575	11.35	1.91×10^{9}
50	10	4.195	999.2	1.31	0.585	9.40	6.34×10^{9}
60	15.56	4.186	998.6	1.12	0.595	7.88	1.08×10^{10}
70	21.11	4.179	997.4	9.8×10^{-4}	0.604	6.78	1.46×10^{10}
80	26.67	4.179	995.8	8.6	0.614	5.85	1.91×10^{10}
90	32.22	4.174	994.9	7.65	0.623	5.12	2.48×10^{10}
100	37.78	4.174	993.0	6.82	0.630	4.53	3.3×10^{10}
110	43.33	4.174	990.6	6.16	0.637	4.04	4.19×10^{10}
120	48.89	4.174	988.8	5.62	0.644	3.64	4.89×10^{10}
130	54.44	4.179	985.7	5.13	0.649	3.30	5.66×10^{10}
140	60	4.179	983.3	4.71	0.654	3.01	6.48×10^{10}
150	65.55	4.183	980.3	4.3	0.659	2.73	7.62×10^{10}
160	71.11	4.186	977.3	4.01	0.665	2.53	8.84×10^{10}
170	76.67	4.191	973.7	3.72	0.668	2.33	9.85×10^{10}
180	82.22	4.195	970.2	3.47	0.673	2.16	1.09×10^{11}
190	87.78	4.199	966.7	3.27	0.675	2.03	
200	93.33	4.204	963.2	3.06	0.678	1.90	
220	104.4	4.216	955.1	2.67	0.684	1.66	

TABLE **Constants for use with Eq. (7-25) for isothermal surfaces**

Geometry	$Gr_f Pr_f$	C	m
Vertical planes and cylinders	10^{-1}–10^{4}	Use Fig. 7-7	Use Fig. 7-7
	10^{4}–10^{9}	0.59	$\frac{1}{4}$
	10^{9}–10^{13}	0.021	$\frac{2}{5}$
	10^{9}–10^{13}	0.10	$\frac{1}{3}$
Horizontal cylinders	0–10^{-5}	0.4	0
	10^{-5}–10^{4}	Use Fig. 7-8	Use Fig. 7-8
	10^{4}–10^{9}	0.53	$\frac{1}{4}$
	10^{9}–10^{12}	0.13	$\frac{1}{3}$
	10^{-10}–10^{-2}	0.675	0.058
	10^{-2}–10^{2}	1.02	0.148
	10^{2}–10^{4}	0.850	0.188
	10^{4}–10^{7}	0.480	$\frac{1}{4}$
	10^{7}–10^{12}	0.125	$\frac{1}{3}$

Summary of empirical relations for free convection in enclosures

Fluid	Geometry	$Gr_\delta Pr$	Pr	$\frac{L}{\delta}$	C	n	m
Liquid	Vertical plate,	< 2000	$k_e/k = 1.0$				
	constant heat	10^{4}–10^{7}	1–20,000	10–40	Eq. 7-52	—	—
	flux or	10^{6}–10^{9}	1–20	1–40	0.046	$\frac{1}{3}$	0
	isothermal						
	Horizontal plate,	< 1700	$k_e/k = 1.0$	—			
	isothermal,	1700–6000	1–5000	—	0.012	0.6	0
	heated from	6000–37,000	1–5000	—	0.375	0.2	0
	below	37,000–10^{8}	1–20		0.13	0.3	0
		> 10^{8}	1–20		0.057	$\frac{1}{3}$	0