UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2011/2012 Academic Session

June 2012

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 TWO printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan DUA 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 <u>ALL</u> questions.
Jawab <u>SEMUA</u> soalan.

1. [a] A wall with a cross sectional area of 4.6 m^2 consists of 17 cm of concrete [k = 1.3 W/m.K], 3.8 cm of fiberglass insulation [k = 0.04 W/m.K], and 0.6 cm of gypsum board [k = 0.05 W/m K]. The inside and outside convection coefficients are 12.9 and 38.2 W/m^2.K, respectively. The outside air temperature is -3°C, and the inside temperature is 17°C. Calculate the:

Sebuah dinding berkeluasan 4.6 m^2 terdiri daripada konkrit [k = 1.3 W/m.K] berketebalan 17 sm, penebat kaca gentian [k = 0.04 W/m.K] berketebalan 3.8 sm dan papan gipsum [k = 0.05 W/m.K] berketebalan 0.6 sm. Pemalar olakan dalam dan luar masing-masing ialah 12.9 dan 38.2 W/m^2.K. Suhu udara di luar dan di dalam masing-masing ialah -3°C dan 17°C. Kirakan:

[i] total thermal resistance
rintangan termal keseluruhan

[ii] heat loss
kehilangan haba

[iii] temperature at the interface between concrete and fiberglass.
suhu di antara permukaan konkrit dan gentian kaca.

[6 marks/markah]

[b] A stainless steel wire (k = 19 W/m.^{o}C) of diameter 10.0 mm, length 1m and surface temperature of 215^{o}C generated heat of 560.2 MW/m^3. Calculate the center temperature of the wire.

Sebuah wayar keluli tahan karat [k = 19 W/m.^{o}C] berdiameter 10.0 mm, panjang 1 m dan mempunyai suhu permukaan 215^{o}C menghasilkan haba sebanyak 560.2 MW/m^3. Kirakan suhu pada bahagian tengah wayar tersebut.

[3 marks/markah]

[c] An electric motor is connected by a horizontal steel shaft (k = 42.56 W/m.K) of 25 mm in diameter to an impeller of a pump that circulates liquid at a temperature of 540^{o}C (Figure Q.1.[c].). If the temperature of the electric motor is limited to a maximum value of 52^{o}C with the ambient air at 27^{o}C and heat transfer coefficient of 40.7 W/m^2.K, what length of shaft should be specified between the motor and the pump?

Sebuah motor elektrik disambung dengan menggunakan aci keluli [k = 42.56 W/m.K] berdiameter 25 mm secara mendatar kepada bilah pam yang mengitarkan cecair bersuhu 540^{o}C (Rajah S.1.[c].). Sekiranya suhu motor elektrik dihad kepada 52^{o}C dengan suhu persekitaran 27^{o}C dan pekali pemindahan haba 40.7 W/m^2.K, berapakah panjang aci yang diperlukan antara motor dan pam?

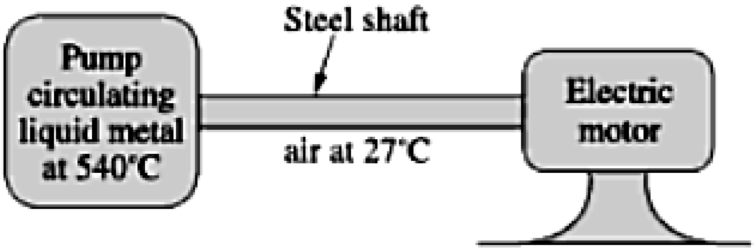

Figure Q.1.[c].
Rajah S.1.[c].

[8 marks/markah]

[d] A furnace has inside dimensions of 20 cm x 20 cm x 20 cm. The walls are 10 cm thick and made of fireclay brick (k = 0.2 W/m.K). Determine the power required for steady operation at a temperature of 900^{o}C when the outside wall temperature is 60^{o}C.

Sebuah relau mempunyai dimensi dalam 20 sm x 20 sm x 20 sm. Dinding relau berketebalan 10 sm dan dibuat daripada bata tanah liat [k = 0.2 W/m.K]. Kirakan kuasa yang diperlukan untuk operasi mantap pada suhu 900^{o}C sekiranya dinding luar bersuhu 60^{o}C.

[4 marks/markah]

[e] A steel plate 2 cm thick is taken from a furnace at 525°C and quenched in a bath of oil at 25°C. If the heat transfer coefficient is estimated to be 360 W/m^2.K, how long will it take for the plate to cool to 50°C?

Sebuah plat keluli berketebalan 2 sm dikeluarkan dari relau pada suhu 525^{o}C dan dilindap-kejut di dalam takungan minyak yang bersuhu 25^{o}C. Sekiranya pemalar pemindahan haba ialah 360 W/m^2.K, berapakah masa yang diperlukan oleh plat tersebut untuk mencapai suhu 50^{o}C?

Given: k, ρ and c_p for the steel as 50 W/m.K, 7800 kg/m^3, and 450 J/kg.K, respectively.

Diberi: k, ρ dan c_p untuk keluli masing-masing sebagai 50 W/m.K, 7800 kg/m^3 dan 450 J/kg.K.

[4 marks/markah]

2. [a] Air at 35^{o}C and 1 atm flows over a flat plate at 45 m/s. The plate is 30 cm long and is maintained at 119^{o}C. Assume unit depth in the z direction. Calculate the heat transfer from the plate.

Udara pada 35^{o}C dan 1 atm mengalir di atas plat mendatar dengan kelajuan 45 m/s. Panjang plat tersebut ialah 30 sm dan bersuhu tetap 119^{o}C. Anggap unit kedalaman adalah dalam arah z. Kirakan pemindahan haba dari plat tersebut.

[6 marks/markah]

[b] Air at 1 atm and 22°C flows across a 2.0 cm diameter and 5 m length cylinder at a velocity of 30 m/s. The cylinder surface is maintained at a temperature of 132°C. Calculate the heat loss of the cylinder.

Udara pada 1 atm dan 22°C mengalir merentasi sebuah silinder yang berdiameter 2.0 sm dan 5 m panjang pada kelajuan 30 m/s. Suhu permukaan silinder adalah tetap pada 132°C. Kirakan kehilangan haba dari silinder tersebut.

[6 marks/markah]

[c] A horizontal pipe 0.3048 m in diameter is maintained at a temperature of 229°C in a room where the ambient air is at 25°C. Calculate the free-convection heat loss per meter of length.

Sebuah paip mendatar berdiameter 0.3048 m dan bersuhu tetap 229°C diletakkan didalam sebuah bilik di mana suhu persekitarannya ialah 25°C. Kirakan kehilangan haba secara perolakan bebas per meter panjang paip tersebut.

[6 marks/markah]

[d] Air at atmospheric pressure is contained between two 0.8-m-square vertical plates separated by a distance of 2.2 cm. The temperatures of the plates are 300°C and 54°C, respectively. Calculate the free-convection heat transfer across the air space.

Udara pada tekanan atmosfera terletak di antara dua plat 0.8-m-segiempat sama secara menegak yang jarak di antara kedua-dua plat tersebut ialah 2.2 sm. Suhu plat adalah masing-masing 300°C dan 54°C. Kirakan pemindahan haba perolakan bebas sepanjang ruang udara tersebut.

[7 marks/markah]

3. [a] Two 50cm diameter parallel discs with equal emissivity of 0.8 are separated from each other at a distance of 12.5cm. Both are placed in a large room at 300K. One disc is maintained at T=1000K and the other T=500K. If the radiation shape factor is 0.59, calculate the heat transfer for each disc (in Watt).

Dua cakera selari bergarispusat 50sm dengan keberpancaran yang sama iaitu 0.8 dipisahkan sejauh 12.5sm di antara satu sama lain. Kedua-duanya diletakkan di bilik yang besar pada 300K. Satu cakera dikekalkan pada T=1000K dan satu lagi pada T=500K. Sekiranya faktor bentuk radiasi ialah 0.59, kirakan pemindahan haba untuk setiap cakera (dalam Watt).

[7 marks/markah]

[b] Two perpendicular square plates with 60cm length are placed in a large room at 30°C. One plate is at T=600°C having emissivity of 0.65. The other plate is insulated having emissivity of 0.45. If the radiation shape factor is 0.2, calculate the temperature of the insulated plate (in K).

Dua plat segiempat-sama dengan panjang 60sm diletakkan di suatu bilik yang besar pada 30°C. Satu plat berada pada 600°C dan keberpancaran 0.65. Plat yang satu lagi ditebat dan mempunyai keberpancaran 0.45. Sekiranya faktor bentuk radiasi ialah 0.2, kirakan suhu plat yang ditebat (dalam K).

[7 marks/markah]

[c] A long cylindrical heater with 2.5cm diameter and emissivity of 0.8 is maintained at 500°C in a large room at 25°C. If the heater is surrounded by a 30cm diameter aluminium shield with emissivity of 0.2, calculate the temperature of the shield (in K).

Suatu pemanas berbentuk silinder bergarispusat 2.5sm dan keberpancaran 0.8 dikekalkan pada 500°C di dalam suatu bilik besar pada suhu 25°C. Sekiranya pemanas tersebut dikelilingi oleh perisai aluminum bergarispusat 30sm dengan keberpancaran 0.2, kirakan suhu perisai (dalam K).

[7 marks/markah]

[d] A slab white marble (α_{sun}=0.46, α_{low}=0.95) is exposed to a solar radiation flux of 1070W/m^2. Assuming the effective radiation temperature of the sky is -70°C, calculate the radiation equilibrium temperature of the slab (in °C).

Suatu kepingan marmar putih (α_{sun}=0.46, α_{low}=0.95) didedahkan kepada fluks radiasi suria 1070W/m^2. Andainya suhu radiasi efektif bagi langit ialah -70°C, kirakan suhu keseimbangan radiasi bagi kepingan tersebut (dalam °C).

[4 marks/markah]

4. [a] A shell and tube heat exchanger having one shell pass and two tube passes is needed to heat 7.5kg/s of water from 85 to 99°C by using steam at 345kPa. The exchanger contains 30 smaller 2.5cm OD tubes. If the overall heat transfer coefficient is 2800 W/m^2.°C, calculate the length of tubes (in meter) required.

Suatu pemindah haba tiub kelompang yang mempunyai satu laluan kelompang dan dua laluan tiub diperlukan untuk memanas 7.5kg/s air daripada 85 ke 99°C menggunakan stim pada 345kPa. Pemindah haba tersebut mempunyai 30 tiub lebih kecil bergarispusat OD 2.5sm. Andainya pekali pemindahan haba keseluruhan ialah 2800 W/m^2.°C, kirakan panjang tiub (dalam meter) yang diperlukan.

Given:
Diberi:

ρ_l=1118 kg/m^3, ρ_g=1.715 kg/m^3, μ=1.72×10^{-4} kg/m.s, h_{fg}=343 kJ/kg
c_w=4175 J/kg.°C, T_{sat}=138°C, k_l=0.1894 W/m.K, $C_{p,l}$=1777 J/kg.°C.

[4 marks/markah]

[b] Liquid CO_2 at 20°C is needed so that it can be easily transported to an offshore platform for permanent sequestration underground. How much CO_2 can be condensed per hour if the gas is contacted with a horizontal 10cm diameter tube at 15°C?

Cecair CO_2 pada 20°C diperlukan supaya ia boleh dibawa ke suatu pelantar luar pantai bagi penyimpanan kekal bawah tanah. Berapa banyakkah CO_2 yang boleh dikodensasikan setiap jam sekiranya gas tersebut bersentuhan dengan tiub melintang bergarispusat 10sm yang dikekalkan pada 15°C?

Given:
Diberi:

$T_f = 17.5^\circ\text{C}$, $\rho = 795\,\text{kg/m}^3$, $h_{fg} = 153.2\,\text{kJ/kg}$, $\mu = 6.87\times10^{-5}\,\text{Ns/m}^2$,
$c_{p,l}$=4214 J/kg.°C, $k = 0.0897\,\text{W/m.K}$, Pr = 3.78

[6 marks/markah]

[c] A shell and tube heat exchanger with effective area of 4.64m^2 and overall heat transfer coefficient of 280 W/m^2.°C is needed to heat water (c_w=4175 J/kg.°C) from 20°C to a temperature not exceeding 93°C. The heating fluid is hot air (c_a=1009 J/kg.°C) entering the exchanger at 260°C with flowrate of 0.45 kg/s. Calculate the water flowrate by starting your calculation using exit water temperature of 65°C.

Suatu pemindah haba kelompang dengan keluasan efektif 4.64m^2 dan pekali pemindahan haba keseluruhan 280 W/m^2.°C diperlukan untuk memanas air (c_w=4175 J/kg.°C) daripada 20°C kepada suhu tidak melebihi 93°C. Bendalir pemanas ialah udara panas (c_a=1009 J/kg.°C) yang memasuki pemindah haba pada 260°C dengan kadar aliran 0.45 kg/s. Kirakan kadar aliran air dengan memulakan perkiraan kamu menggunakan suhu air keluar pada 65°C.

[8 marks/markah]

[d] Calculate the rate of steam condesation (in kg/s per meter depth) when the gas is in contact with a vertical plate maintained at 91°C, 1 atm.

Kirakan kadar stim terkondensasi (dalam kg/s per meter kedalaman) apabila gas tersebut bersentuhan dengan plat menegak yang dikekalkan pada 91°C, 1 atm.

Given:
Diberikan:

ρ_l = 961 kg/m^3, h_{fg} = 2255 kJ/kg, ρ_v = 4.808 kg/m^3, $c_{p,v}$ = 2.56 kJ/kg.°C,
k_v = 0.68 W/m.K, μ_v = 2.97×10^{-4} N.s/m^2, C = 1.13, Re = 1800
$\sigma = 5.669\times10^{-8}$ W/m^2.K^4

[7 marks/markah]

- oooOooo -

Appendix

$$T_x = T_w + \frac{R^2 q'''}{4k}\left[1 - \frac{r_x^2}{R^2}\right]$$

$M = \sqrt{hPkA}\left(T_b - T_\infty\right)$; m^2=hP/kA; $\dfrac{T_x - T_\infty}{T_b - T_\infty} = \dfrac{\cosh m(L-x)}{\cosh mL}$; q= M tanh (mL)

S_{wall} = A/L; S_{edge}=0.54D; S_{corner} =0.15L

$Bi = \dfrac{h\left(V/A\right)}{k}$; $\tau_c = \dfrac{\rho c V}{hA_{conv}} = \dfrac{\rho c L_c}{h}$; $\dfrac{T - T_\infty}{T_o - T_\infty} = e^{-(hA/C\rho V)\tau}$

Plate, laminar flow : $Nu_x = 0.66\,\mathrm{Pr}^{1/3}\,\mathrm{Re}_x^{1/2}$

Plate, turbulent flow : $Nu_x = \mathrm{Pr}^{1/3}(0.037\,\mathrm{Re}_x^{0.8} - 871)$

$Nu = \dfrac{hd}{k} = C(\mathrm{Re})^n\,\mathrm{Pr}^{1/3}$;

$Gr\,\mathrm{Pr} = \left(\dfrac{g\beta(T_w - T_\infty)d^3}{v^2}\right)\mathrm{Pr}$; $Nu = C(Gr\ \mathrm{Pr})^m$

$Gr\,\mathrm{Pr} = \left(\dfrac{g\beta(T_1 - T_2)\delta^3}{v^2}\right)\mathrm{Pr}$; $k_e = kC(Gr\,\mathrm{Pr})^n\left(\dfrac{L}{\delta}\right)^m$; $q = \dfrac{k_e A(T_1 - T_2)}{\delta}$

$\bar{h}_L = 0.943\left[\dfrac{g\rho_l\,(\rho_l - \rho_\upsilon)\,k_l^{\,3} h'_{fg}}{\mu_l\,(\Delta T)\,L}\right]^{1/4}$, $q = \bar{h}_L A(\Delta T)$, $\mathrm{Re}_\delta = \dfrac{4\dot{m}}{\mu_l b}$, $\overset{o}{m} = \dfrac{\bar{h}A\left(T_g - T_w\right)}{h_{fg}}$

$q' = \mu_l h_{fg}\left[\dfrac{g\left(\rho_l - \rho_v\right)}{\sigma'}\right]^{1/2}\left(\dfrac{c_{p,l}\Delta T_x}{C_{sf}\,h_{fg}\,\mathrm{Pr}_l^{\,s}}\right)^3$, $\dfrac{\bar{h}\left(v^2/g\right)^{1/3}}{k_l} = 1.47\,\mathrm{Re}^{-1/3}$

$h^{4/3} = h_{conv}^{\;4/3} + h_{rad}h^{1/3}$, $\dfrac{\bar{h}\left(v^2/g\right)^{1/3}}{k_l} = \dfrac{\mathrm{Re}}{1.08\,\mathrm{Re}^{1.22} - 5.2}$

$h_{conv} = \dfrac{Ck_v}{D}\left[\dfrac{g\left(\rho_l - \rho_v\right)h_{fg}D^3}{\nu_v k_v\left(T_s - T_{sat}\right)}\right]^{1/4}$, $\dfrac{\bar{h}\left(v^2/g\right)^{1/3}}{k_l} = \dfrac{\mathrm{Re}}{8750 + 58\,\mathrm{Pr}^{-0.5}\left(\mathrm{Re}^{0.75} - 253\right)}$

$h_{rad} = \dfrac{\varepsilon\sigma\left(T_s^{\;4} - T_{sat}^{\;4}\right)}{\left(T_s - T_{sat}\right)}$, $\bar{h} = 0.725\left[\dfrac{\rho_l\left(\rho_l - \rho_v\right)gh_{fg}k_l^3}{N\mu_l\left(T_{sat} - T_s\right)D}\right]^{1/4}$, $\bar{h} = C\left[\dfrac{\rho_l\left(\rho_l - \rho_v\right)gh_{fg}k_l^3}{\mu_l\left(T_{sat} - T_s\right)L}\right]^{1/4}$

Re_{df}	C	n
0.4–4	0.989	0.330
4–40	0.911	0.385
40–4000	0.683	0.466
4000–40,000	0.193	0.618
40,000–400,000	0.0266	0.805

Geometry	$Gr_f Pr_f$	C	m
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

free convection in enclosures

Fluid	Geometry	$Gr_\delta Pr$	Pr	$\frac{L}{\delta}$	C	n	m	Ref(s).
Gas	Vertical plate, isothermal	< 2000	$k_e/k = 1.0$					6, 7, 55, 59
		6000–200,000	0.5–2	11–42	0.197	$\frac{1}{4}$	$-\frac{1}{9}$	
		$200,000–1.1 \times 10^{7}$	0.5–2	11–42	0.073	$\frac{1}{3}$	$-\frac{1}{9}$	
	Horizontal plate, isothermal heated from below	< 1700	$k_e/k = 1.0$					
		1700–7000	0.5–2	—	0.059	0.4	0	6, 7, 55, 59, 62, 63
		$7000–3.2 \times 10^{5}$	0.5–2	—	0.212	$\frac{1}{4}$	0	66
		$> 3.2 \times 10^{5}$	0.5–2	—	0.061	$\frac{1}{3}$	0	

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