UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2006/2007

April 2007

EKC 213 – Pemindahan Haba Proses

Masa : 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi LIMA muka surat yang bercetak dan SEMBILAN muka surat Lampiran sebelum anda memulakan peperiksaan ini.

Arahan: Jawab **EMPAT** **(4)** soalan.

PELAJAR DIBENARKAN MENJAWAB SOALAN SAMA ADA DALAM BAHASA MALAYSIA ATAU BAHASA INGGERIS.

...2/-

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Derive an expression for the thermal resistance through a hollow spherical shell of inside radius r_i and outside radius r_o having thermal conductivity K.

[5 marks]

[b] A spherical tank used for an experimental test is constructed of aluminum with an inner diameter of 0.04 m and an outer diameter of 0.08 m. The inside temperature is 100°C and the outer temperature 50°C. If the thermal conductivity of aluminum is 204 W/m K.

[i] Calculate the heat transfer from the inside to the outside of the tank.

[ii] Calculate the aluminum tank thermal resistance.

[10 marks]

[c] Assume that the sphere in above question [b] is covered with a 1.0 cm layer of an insulating material having thermal conductivity 0.05 W/m K and the outside of the insulation is exposed to an environment with heat-transfer coefficient is equal to 20 W/m^2 K and temperature is 10°C. The inside of the sphere remains at 100°C. Calculate:-

[i] the insulating material thermal resistance.

[ii] the heat-transfer under these conditions.

[10 marks]

1. [a] Terbitkan ungkapan bagi rintangan haba melalui sebuah kelompong sfera geronggang yang mempunyai jejari dalam r_i dan jejari luar r_o dan keberaliran haba K.

[5 markah]

[b] Sebuah tangki sfera yang digunakan bagi suatu ujikaji dibina dari aluminium dengan garispusat dalaman 0.04 m dan garispusat luaran 0.08 m. Suhu dalam ialah 100°C dan suhu luar ialah 50°C. Jika keberaliran haba aluminium ialah 204 W/m K.

[i] Kirakan pemindahan haba dari bahagian dalam ke bahagian luar tangki.

[ii] Kirakan rintangan haba tangki aluminium.

[10 markah]

[c] Andaikan sfera di soalan [b] ditutupi dengan lapisan 1.0 sm suatu bahan penebat yang mempunyai keberaliran haba sebanyak 0.05 W/m K. Bahagian luar penebat didedahkan kepada suatu persekitaran dengan pekali pemindahan haba bersamaan 20 W/m^2 K dan suhu 10°C. Bahagian dalam sfera kekal pada 100°C. Kirakan:-

[i] rintangan haba bahan penebat.

[ii] pemindahan haba di bawah keadaan-keadaan tersebut.

[10 markah]

...3/-

2. [a] The area of the flat roof of a building is 30.0 m × 60.0 m and the surface temperature is measured to be 27°C due to the attainment of heat loading by the sun. The ambient air temperature in that time is found to be 0°C. In order to use the rules of the principle of convection heat transfer it is necessary to measure the velocity of the mild breeze blowing across the roof and is found to be 5 miles per hour. Calculate the heat lost from the roof.

[8 marks]

[b] A tube bank consists of a square array of 144 tubes arranged in an in-line position. The tubes have a diameter of 1.5 cm and length of 1.0 m. The center-to-center tube spacing is 2.0 cm. If the surface temperature of the tubes is maintained at 350 K and air enters the tube bank at 1.0 bar, temperature 300 K and air velocity $U_\infty = 6$ m/s, calculate:-

[i] the air exit temperature

[ii] the total heat lost by the tube

[10 marks]

[c] A sphere with 25 mm diameter is maintained at a surface temperature of 50°C and exposed to a fluid at 27°C. Calculate the heat loss for,

[i] air

[ii] water

[7 marks]

2. [a] Luas bumbung rata sebuah bangunan ialah 30.0 m × 60.0 m dan suhu permukaan yang diukur adalah 27°C yang disebabkan oleh bebanan haba matahari. Suhu udara ambien pada masa tersebut adalah 0°C. Untuk menggunakan aturan-aturan bagi prinsip pemindahan haba olakan, halaju bayu yang bertiup merentasi bumbung perlu diukur dan ia didapati bernilai 5 batu per jam. Kirakan haba yang hilang dari bumbung.

[8 markah]

[b] Sekumpulan tiub dengan tatasusunan segiempat sama mengandungi 144 tiub yang diatur dalam kedudukan sebaris. Tiub-tiub tersebut mempunyai garispusat 1.5 sm dan panjang 1.0 m. Jarak pusat-ke-pusat tiub ialah 2.0 sm. Jika suhu dipermukaan tiub-tiub dikekalkan pada 350 K dan udara memasuki kumpulan tiub pada 1.0 bar, suhu 300K dan halaju udara $U_\infty = 6$ m/s, kirakan

[i] suhu keluar udara

[ii] jumlah haba yang hilang dari tiub

[10 markah]

[c] Suatu sfera dengan garispusat 25 mm dan suhu permukaan yang dikekalkan pada 50°C didedahkan kepada suatu bendalir pada 27°C. Kirakan kehilangan haba bagi,

[i] udara

[ii] air

[7 markah]

...4/-

3. Two parallel planes 1.2 m × 1.2 m are separated by a distance of 1.2 m. The emissivities of the planes are 0.4 ($0 \le \lambda \le 70$ μm) and 0.6 ($0 \le \lambda \le 100$ μm), and the temperatures are 760°C and 300°C, respectively. A 1.2 m × 1.2 m radiation shield having an emissivity of 0.05 on both sides is located equidistant between the two planes. The combined arrangement is placed in a large room which is maintained at 40°C. Calculate:

[a] The heat-transfer rate from each of the two planes if the shield were not present

[5 marks]

[b] The heat-transfer rate from each of the two planes with the shield present

[9 marks]

[c] The temperature of the shield

[5 marks]

[d] Wavelength and spectral emissive power (per unit area per unit wavelength) associated with maximum emission to the room.

[6 marks]

3. *Dua satah yang berjajar bersaiz 1.2 m × 1.2 m dipisahkan sejauh 1.2 m. Keberpancaran satah-satah berkenaan ialah masing-masing 0.4 ($0 \le \lambda \le 70$ μm) dan 0.6 ($0 \le \lambda \le 100$ μm), dan suhu 760°C dan 300°C. Satu perisai radiasi bersaiz 1.2 m × 1.2 m mempunyai keberpancaran 0.05 di kedua-dua bahagian diletakkan di tengah-tengah dua satah. Kombinasi aturan ini diletakkan di suatu bilik yang luas pada 40°C. Kirakan:*

[a] Kadar pemindahan haba daripada setiap satu satah sekiranya tiada perisai.

[5 markah]

[b] Kadar pemindahan haba daripada setiap satu satah dengan perisai.

[9 markah]

[c] Suhu perisai tersebut

[5 markah]

[d] Panjang gelombang dan kuasa pancaran spektrum (per unit keluasan per panjang gelombang) berkaitan dengan pancaran maksimum terhadap bilik tersebut.

[6 markah]

4. [a] A large condenser is designed to remove 800 MW of energy from condensing steam at 1 atm pressure. To accomplish this task, cooling water enters the condenser at 25°C and leaves at 30°C. The overall heat transfer coefficient (U) is 2000 W/m^2.°C. Calculate the area required for the heat exchanger.

[10 marks]

[b] Suppose the water flow rate for part [a] above is reduced in half from the design value. What will be the steam condensation rate (in kg/hr) under these conditions if the overall heat transfer coefficient (U) remains the same? Given:

$h_{fg} = 2.255 \times 10^6$ J/kg
$C_{p,d} = 4.217$ kJ/kg.K
$J = 58.9 \times 10^{-3}$ N/m
$C_{sf} = 0.0130$
$K_v = 0.0331$ W/m.K
$B = \frac{1}{T}$ if the fluid behaves ideally

[15 marks]

4. [a] Suatu pemeluwap yang bersaiz besar direkabentuk untuk mengeluarkan 800 MW tenaga daripada pemeluwapan stim pada tekanan 1 atm. Bagi mencapai tujuan ini, air penyejuk memasuki pemeluwap pada 25°C dan meninggalkan pemeluwap pada 30°C. Pekali pemindahan haba keseluruhan (U) ialah 2000 W/m^2.°C. Kirakan keluasan penukar haba yang diperlukan.

[10 markah]

[b] Sekiranya kadar pengaliran air di bahagian [a] di atas dikurangkan kepada separuh daripada nilai reka bentuk. Berapakah kadar pemeluwapan stim (dalam kg/jam) pada keadaan seperti di atas sekiranya U dikekalkan? Diberi:

$h_{fg} = 2.255 \times 10^6$ J/kg
$C_{p,d} = 4.217$ kJ/kg.K
$J = 58.9 \times 10^{-3}$ N/m
$C_{sf} = 0.0130$
$K_v = 0.0331$ w/m.K
$B = \frac{1}{T}$ *sekiranya bendalir bersifat unggul*

[15 markah]

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Lampiran

Table 1 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/m³	c_p kJ/kg · °C	$\mu \times 10^5$ kg/m · s	$\nu \times 10^6$ m²/s	k W/m · °C	$\alpha \times 10^4$ m²/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
550	0.6423	1.0392	2.848	44.34	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.680
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.3	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06525	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702
1100	0.3204	1.160	4.44	138.6	0.0732	1.969	0.704
1200	0.2947	1.179	4.69	159.1	0.0782	2.251	0.707
1300	0.2707	1.197	4.93	182.1	0.0837	2.583	0.705
1400	0.2515	1.214	5.17	205.5	0.0891	2.920	0.705
1500	0.2355	1.230	5.40	229.1	0.0946	3.262	0.705
1600	0.2211	1.248	5.63	254.5	0.100	3.609	0.705
1700	0.2082	1.267	5.85	280.5	0.105	3.977	0.705
1800	0.1970	1.287	6.07	308.1	0.111	4.379	0.704
1900	0.1858	1.309	6.29	338.5	0.117	4.811	0.704
2000	0.1762	1.338	6.50	369.0	0.124	5.260	0.702
2100	0.1682	1.372	6.72	399.6	0.131	5.715	0.700
2200	0.1602	1.419	6.93	432.6	0.139	6.120	0.707
2300	0.1538	1.482	7.14	464.0	0.149	6.540	0.710
2400	0.1458	1.574	7.35	504.0	0.161	7.020	0.718
2500	0.1394	1.688	7.57	543.5	0.175	7.441	0.730

Table 2 Properties of Water (Saturated Liquid)†

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

°F	°C	c_p, kJ/kg K	ρ, kg/m³	μ, kg/m s	k, W/m K	Pr	$\dfrac{g\beta\rho^2 c_p}{\mu k}$, 1/m³ K
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	
240	115.6	4.229	946.7	2.44	0.685	1.51	
260	126.7	4.250	937.2	2.19	0.685	1.36	
280	137.8	4.271	928.1	1.98	0.685	1.24	
300	148.9	4.296	918.0	1.86	0.684	1.17	
350	176.7	4.371	890.4	1.57	0.677	1.02	
400	204.4	4.467	859.4	1.36	0.665	1.00	
450	232.2	4.585	825.7	1.20	0.646	0.85	
500	260	4.731	785.2	1.07	0.616	0.83	
550	287.7	5.024	735.5	9.51×10^{-5}			
600	315.6	5.703	678.7	8.68			

Convection heat transfer equations

(1) $Nu = (Pr)^{1/3}\ (0.037\,(Re)^{0.8} - 871)$

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(2) $Nu = C\ (Re)^{n}\ (Pr)^{1/3}$ Where $C = 0.364$ and $n = 0.597$

Also where $(S_n / d) = (S_p) = 1.33$

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(3) Rayleigh Number $Ra = g\ \beta\,(Tw - T\infty)\,\delta^3\,Pr\ /\ \upsilon^2$ Where $g = 9.8$

$Ra = Gr\ .\ Pr$

$Nu = C\ (Gr\ .\ Pr)^{m}$ Where $C = 0.15$ and $m = 1/3$

(4) For Sphere in Air $Nu = 2 + 0.43\,(Gr.\ Pr)^{1/4}$

For Sphere in Water $Nu = 2 + 0.5\,(Gr.\ Pr)^{1/4}$

Air gas constant $R = 287$ J /kg K

Air specific heat at constant pressure = 1.005 kJ /kg K

Table 1 Properties of air at atmospheric pressure

Table 2 Properties of water (Saturated liquid)

Table Radiation function

λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2K^5\mu m\times10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$	λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2K^5\mu m\times10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$
1000	0.02110	0.00032	5100	0.68628	0.64606
1100	0.04846	0.00091	5200	0.65983	0.65794
1200	0.09329	0.00213	5300	0.63432	0.66935
1300	0.15724	0.00432	5400	0.60974	0.68033
1400	0.23932	0.00779	5500	0.58608	0.69087
1500	0.33631	0.01285	5600	0.56332	0.70101
1600	0.44359	0.01972	5700	0.54146	0.71076
1700	0.55603	0.02853	5800	0.52046	0.72012
1800	0.66872	0.03934	5900	0.50030	0.72913
1900	0.77736	0.05210	6000	0.48096	0.73778
2000	0.87858	0.06672	6100	0.46242	0.74610
2100	0.96994	0.08305	6200	0.44464	0.75410
2200	1.04990	0.10088	6300	0.42760	0.76180
2300	1.11768	0.12002	6400	0.41128	0.76920
2400	1.17314	0.14025	6500	0.39564	0.77631
2500	1.21659	0.16135	6600	0.38066	0.78316
2600	1.24868	0.18311	6700	0.36631	0.78975
2700	1.27029	0.20535	6800	0.35256	0.79609
2800	1.28242	0.22788	6900	0.33940	0.80219
2900	1.28612	0.25055	7000	0.32679	0.80807
3000	1.28245	0.27322	7100	0.31471	0.81373
3100	1.27242	0.29576	7200	0.30315	0.81918
3200	1.25702	0.31809	7300	0.29207	0.82443
3300	1.23711	0.34009	7400	0.28146	0.82949
3400	1.21352	0.36172	7500	0.27129	0.83436
3500	1.18695	0.38290	7600	0.26155	0.83906
3600	1.15806	0.40359	7700	0.25221	0.84359
3700	1.12739	0.42375	7800	0.24326	0.84796
3800	1.09544	0.44336	7900	0.23468	0.85218
3900	1.06261	0.46240	8000	0.22646	0.85625
4000	1.02927	0.48085	8100	0.21857	0.86017
4100	0.99571	0.49872	8200	0.21101	0.86396
4200	0.96220	0.51599	8300	0.20375	0.86762
4300	0.92892	0.53267	8400	0.19679	0.87115
4400	0.89607	0.54877	8500	0.19011	0.87456
4500	0.86376	0.56429	8600	0.18370	0.87786
4600	0.83212	0.57925	8700	0.17755	0.88105
4700	0.80124	0.59366	8800	0.17164	0.88413
4800	0.77117	0.60753	8900	0.16596	0.88711
4900	0.74197	0.62088	9000	0.16051	0.88999
5000	0.71366	0.63372	9100	0.15527	0.89277

Table Radiation function (continue)

λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2K^5\mu m\times10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$	λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2K^5\mu m\times10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$
9200	0.15024	0.89547	16600	0.02152	0.97620
9300	0.14540	0.89807	16800	0.02063	0.97694
9400	0.14075	0.90060	17000	0.01979	0.97765
9500	0.13627	0.90304	17200	0.01899	0.97834
9600	0.13197	0.90541	17400	0.01823	0.97899
9700	0.12783	0.90770	17600	0.01751	0.97962
9800	0.12384	0.90992	17800	0.01682	0.98023
9900	0.12001	0.91207	18000	0.01617	0.98081
10000	0.11632	0.91415	18200	0.01555	0.98137
10200	0.10934	0.91813	18400	0.01496	0.98191
10400	0.10287	0.92188	18600	0.01439	0.98243
10600	0.09685	0.92540	18800	0.01385	0.98293
10800	0.09126	0.92872	19000	0.01334	0.98340
11000	0.08606	0.93184	19200	0.01285	0.98387
11200	0.08121	0.93479	19400	0.01238	0.98431
11400	0.07670	0.93758	19600	0.01193	0.98474
11600	0.07249	0.94021	19800	0.01151	0.98515
11800	0.06856	0.94270	20000	0.01110	0.98555
12000	0.06488	0.94505	21000	0.00931	0.98735
12200	0.06145	0.94728	22000	0.00786	0.98886
12400	0.05823	0.94939	23000	0.00669	0.99014
12600	0.05522	0.95139	24000	0.00572	0.99123
12800	0.05240	0.95329	25000	0.00492	0.99217
13000	0.04976	0.95509	26000	0.00426	0.99297
13200	0.04728	0.95680	27000	0.00370	0.99367
13400	0.04494	0.95843	28000	0.00324	0.99429
13600	0.04275	0.95998	29000	0.00284	0.99482
13800	0.04069	0.96145	30000	0.00250	0.99529
14000	0.03875	0.96285	31000	0.00221	0.99571
14200	0.03693	0.96418	32000	0.00196	0.99607
14400	0.03520	0.96546	33000	0.00175	0.99640
14600	0.03358	0.96667	34000	0.00156	0.99669
14800	0.03205	0.96783	35000	0.00140	0.99695
15000	0.03060	0.96893	36000	0.00126	0.99719
15200	0.02923	0.96999	37000	0.00113	0.99740
15400	0.02794	0.97100	38000	0.00103	0.99759
15600	0.02672	0.97196	39000	0.00093	0.99776
15800	0.02556	0.97288	40000	0.00084	0.99792
16000	0.02447	0.97377	41000	0.00077	0.99806
16200	0.02343	0.97461	42000	0.00070	0.99819
16400	0.02245	0.97542	43000	0.00064	0.99831

…5/-

Table Radiation function (continue)

λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2K^5\mu m\times10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$
44000	0.00059	0.99842
45000	0.00054	0.99851
46000	0.00049	0.99861
47000	0.00046	0.99869
48000	0.00042	0.99877
49000	0.00039	0.99884
50000	0.00036	0.99890

System of unit conversion

Quantity	Equivalent unit
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 Ib_m = 35.27392 ounces 1 Ib_m = 16 ounces = 5×10^{-4} tons = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 µm = 10^{10} angstrom = 39.37 in = 3.2808 ft = 1.0936 yards = 0.0006214 mile.
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6ml = 35.3145 ft^3 = 264.17 gal 1 ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28317 cm^3
Force	1 N = 1 kg.m.s^{-2} = 10^5 dyne = 10^5 g.cm.s^{-2} = 0.22481 Ib_f 1 Ib_f = 32.174 Ib_m ft.s^{-2} = 4.4482 N
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 1.01325×10^5 kg/(m.s^2) = 760 torr = 760 mmHg = 14.696 psi = 1.01325 bar
Energy	1 J = 1 N.m = 10^7 dyne.cm = 2.778×10^{-7} kW.h = 0.23901 kal = 0.7376 ft-Ib_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft-Ib_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Gas constant	Other constant
8.314 m^3.Pa/mol.K	h = 6.625×10^{-34}Js (Plank's constant)
0.08314 liter. bar/mol.K	σ = 5.669×10^{-8} (Stefan-Boltzman constant)
0.08206 liter.atm/mol.K	$C_1 = 3.743\times10^8$ Wµ/m^2
62.36 liter.mmHg/mol.K	$C_2 = 1.4387\times10^8$ µmK
0.7302 ft^3 atm/Ib-mole.°R	$C_3 = 2897.6$ µmK
10.73 ft^3.psia/Ib-mole.°R	
82.06 cm^3.atm/mol.K	
8.314 J/mol.K	
1.987 cal/mol.K	
1.987 Btu/Ib-mole.°R	

Table Heat-exchanger effectiveness relations.

$N = \mathrm{NTU} = \frac{UA}{C_{min}}$ $C = \frac{C_{min}}{C_{max}}$

Flow geometry	Relation
Double pipe:	
Parallel flow	$\epsilon = \frac{1 - \exp[-N(1 + C)]}{1 + C}$
Counterflow	$\epsilon = \frac{1 - \exp[-N(1 - C)]}{1 - C\exp[-N(1 - C)]}$
Counterflow, $C = 1$	$\epsilon = \frac{N}{N + 1}$
Cross flow:	
Both fluids unmixed	$\epsilon = 1 - \exp\left[\frac{\exp(-NCn) - 1}{Cn}\right]$ where $n = N^{-0.22}$
Both fluids mixed	$\epsilon = \left[\frac{1}{1 - \exp(-N)} + \frac{C}{1 - \exp(-NC)} - \frac{1}{N}\right]^{-1}$
C_{max} mixed, C_{min} unmixed	$\epsilon = (1/C)\{1 - \exp[-C(1 - e^{-N})]\}$
C_{max} unmixed, C_{min} mixed	$\epsilon = 1 - \exp\{-(1/C)[1 - \exp(-NC)]\}$
Shell and tube:	
One shell pass, 2, 4, 6, tube passes	$\epsilon = 2\left\{1 + C + (1 + C^2)^{1/2} \times \frac{1 + \exp[-N(1 + C^2)^{1/2}]}{1 - \exp[-N(1 + C^2)^{1/2}]}\right\}^{-1}$
Multiple shell passes, $2n$, $4n$, $6n$ tube passes (ϵ_p = effectiveness of each shell pass, n = number of shell passes)	$\epsilon = \frac{[(1 - \epsilon_p C)/(1 - \epsilon_p)]^n - 1}{[(1 - \epsilon_p C)/(1 - \epsilon_p)]^n - C}$
Special case for $C = 1$	$\epsilon = \frac{n\epsilon_p}{1 + (n - 1)\epsilon_p}$
All exchangers with $C = 0$	$\epsilon = 1 - e^{-N}$

Table NTU relations for heat exchangers.

$C = C_{min}/C_{max}$ ϵ = effectiveness $N = \mathrm{NTU} = UA/C_{min}$

Flow geometry	Relation
Double pipe:	
Parallel flow	$N = \frac{-\ln[1 - (1 + C)\epsilon]}{1 + C}$
Counterflow	$N = \frac{1}{C - 1}\ln\left(\frac{\epsilon - 1}{C\epsilon - 1}\right)$
Counterflow, $C = 1$	$N = \frac{\epsilon}{1 - \epsilon}$
Cross flow:	
C_{max} mixed, C_{min} unmixed	$N = -\ln\left[1 + \frac{1}{C}\ln(1 - C\epsilon)\right]$
C_{max} unmixed, C_{min} mixed	$N = \frac{-1}{C}\ln[1 + C\ln(1 - \epsilon)]$
Shell and tube:	
One shell pass, 2, 4, 6, tube passes	$N = -(1 + C^2)^{-1/2} \times \ln\left[\frac{2/\epsilon - 1 - C - (1 + C^2)^{1/2}}{2/\epsilon - 1 - C + (1 + C^2)^{1/2}}\right]$
All exchangers, $C = 0$	$N = -\ln(1 - \epsilon)$

$$\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = 1.47\,\mathrm{Re}^{-1/3}$$

$$\mathrm{Re} = \frac{4\dot{m}}{\mu_l b}$$

$$\delta(x) = \left[\frac{4k_l\mu_l(T_{sat} - T_s)x}{g\rho_l(\rho_l - \rho_v)h_{fg}}\right]^{1/4}$$

$$\bar{h} = 0.943\left[\frac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{\mu_l(T_{sat} - T_s)L}\right]^{1/4}$$

$$\Delta \mathrm{p} = \frac{v_1 G^2}{2g_c}\left[(1+\sigma^2)\left(\frac{v_2}{v_1} - 1\right) + f\frac{A}{A_c}\frac{v_m}{v_1}\right]$$

$$G = \frac{\dot{m}}{A_c} = \frac{\rho u_\infty A}{A_c}$$

$$Re = \frac{D_h G}{\mu}$$

$$\sigma = \frac{A_c}{A}$$

$$\mathrm{St} = \frac{h}{Gc_p}$$

$$\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = \frac{\mathrm{Re}}{1.08\,\mathrm{Re}^{1.22} - 5.2}$$

$$\mathrm{Gr} = \frac{\rho^2 g\beta(\Delta T)d^3}{\mu^2}$$

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$

$$\bar{h} = c\left[\frac{\rho_l(\rho_l - \rho_v)gh_{fg}'k_l^3}{N\mu_l(T_{sat} - T_s)D}\right]^{1/4}$$, where c=0.726 (on tube), c=0.555 (in tube)

$$h_{fg}' = h_{fg} + 0.375c_{p,l}(T_{sat} - T_s)$$

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

$$\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = \frac{\mathrm{Re}}{8750 + 58\,\mathrm{Pr}^{-0.5}(\mathrm{Re}^{0.75} - 253)}$$

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$h^{4/3} = h_{conv}{}^{4/3} + h_{rad} h^{1/3}$ $h_{conv} = \frac{Ck_v}{D}\left[\frac{g(\rho_l - \rho_v)h_{fg} D^3}{\nu_v k_v (T_s - T_{sat})}\right]^{1/4}$ $C = 0.62$ (horizontal cylinder), 0.67 (sphere)
$h_{rad} = \frac{\varepsilon\sigma(T_s{}^4 - T_{sat}{}^4)}{(T_s - T_{sat})}$
$\frac{q}{A} = 2.253(\Delta T_x)^{3.96}$ W/m^2 ; $2 < p < 6$ atm $\frac{q}{A} = 283.2 p^{4/3}(\Delta T_x)^3$ W/m^2 ; $8 < p < 14$ atm
$h = 2.54(\Delta T_x)^3 e^{p/1.551}$
$\frac{q}{A} = 2.253(\Delta T_x)^{3.96}$

Figure Radiation shape factor for radiation between parallel rectangles.