UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2005/2006

April/Mei 2006

EKC 213 – Pemindahan Haba Proses

Masa : 3 jam

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

Arahan: Jawab **LIMA** (5) soalan. Jawab **SEMUA** soalan dari Bahagian A. Jawab mana-mana **DUA** (2) soalan dari Bahagian B.

Pelajar boleh menjawab semua soalan dalam Bahasa Malaysia. Jika pelajar ingin menjawab dalam Bahasa Inggeris, pelajar hendaklah menjawab sekurang-kurangnya SATU soalan dalam Bahasa Malaysia.

...2/-

Bahagian A : Jawab SEMUA soalan.
Section A : Answer ALL questions.

1. [a] Satu dinding satah, ia pada permulaannya berada pada suhu seragam dengan satu sisi pada 100°C, manakala satu sisi lagi didedahkan kepada satu proses perolakan dengan suatu bendalir pada suhu 10°C, mempunyai pekali pemindahan haba perolakan 10.0 W/m^{2}K. Dinding tersebut mempunyai keberaliran haba 1.6 W/mK dan berketebalan 40 sm. Kirakan

[i] Kadar pemindahan haba melalui dinding tersebut.

[4 markah]

[ii] Suhu dinding pada sisi sebelahnya.

[4 markah]

[b] Satu tangki sfera untuk penyimpanan oksigen cecair di dalam kapal angkasa dengan diameternya 8 sm telah dipanaskan ke suhu 150°C dan dipasang di dalam ruangan besar yang mana suhu ruang tersebut disenggarakan pada 20°C. Keberpancaran permukaan adalah 0.65 dan Pekali Stefan Boltzman adalah 5.669 x 10^{-8} W/mK^4. Kirakan

[i] Kehilangan haba radiasi.

[4 markah]

[ii] Suhu ruangan besar jika kehilangan haba adalah 1.76 kW.

[5 markah]

1. [a] A plane wall is initially at a uniform temperature with one side at 100°C, while the other side is exposed to a convection process with a fluid at temperature 10°C, having a convection heat-transfer coefficient of 10.0 W/m^{2}K. The wall has a thermal conductivity of 1.6 W/mK and is 40 cm thick. Calculate

[i] The heat-transfer rate through the wall.

[4 marks]

[ii] The temperature of the other side of the wall.

[4 marks]

[b] A spherical tank for storing liquid oxygen on the space shuttle with 8 cm diameter is heated to a temperature of 150°C and is installed in a large compartment whose temperature is to be maintained at 20°C. The surface emissivity is 0.65 and Stefan Boltzman constant is 5.669 x 10^{-8} W/mK^4. Calculate

[i] The radiant heat loss.

[4 marks]

[ii] The large compartment temperature if the radiant heat loss is 1.76 kW.

[5 marks]

...3/-

2. [a] Tangki kontena sfera digunakan untuk suatu ujikaji telah dibina menggunakan aluminium dengan diameter dalaman 0.04 m dan diameter luaran 0.08 m. Suhu dalaman adalah 100°C dan suhu luaran adalah 50°C. Jika keberaliran haba Aluminium adalah 204 W/mK, kirakan:

[i] Pemindahan haba dari dalaman ke luaran kontena tersebut.

[4 markah]

[ii] Rintangan haba kontena aluminium tersebut.

[4 markah]

[b] Anggap bahawa sfera dalam soalan [a] diselaputi dengan 1.0 sm lapisan bahan penebat yang mempunyai keberaliran haba 0.05 W/mK dan luaran penebat didedahkan kepada persekitaran dengan pekali pemindahan haba bersamaan 20 W/m^2K dan pada suhu 10°C. Dalaman sfera tersebut kekal pada suhu 100°C. Kirakan

[i] Rintangan haba bahan penebat.

[4 markah]

[ii] Kadar pemindahan haba di bawah keadaan tersebut.

[5 markah]

2. [a] A spherical container tank used for an experimental test is constructed of aluminium 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 Aluminium is 204 W/mK, calculate:

[i] The heat transfer from the inside to the outside of the container

[4 marks]

[ii] The thermal resistance of the aluminum container

[4 marks]

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

[i] The thermal resistance of the insulating material.

[4 marks]

[ii] The heat-transfer rate under these conditions.

[5 marks]

...4/-

3. [a] Bagi menguji prinsip pemindahan haba perolakan, Helium diperlukan bagi ujian tersebut pada tekanan 150 kPa dan suhu 20°C mengalir merentasi plat berkeluasan 1.0 m^2 dan pada halaju 50 m/s. Plat dikekalkan pada suhu 100°C. Kirakan haba yang hilang dari plat tersebut (anggapkan panjang bersamaan dengan satu meter).

[5 markah]

[b] Etilena glikol perlu disejukkan dari 60 ke 40°C dalam tiub berdiameter 3 sm bagi ujian pemindahan haba perolakan. Suhu dinding tiub dikekalkan pada suhu 20°C. Gliko tersebut memasuki tiub dengan halaju 10 m/s. Kirakan panjang tiub yang diperlukan untuk penyejukan paksa ini.

[5 markah]

[c] Satu pemanas minyak-enjin terdiri daripada tangki besar dengan satu pemanas elektrik berpermukaan plat segiempat sama di bahagian bawah tangki tersebut. Plat pemanas bersaiz 30 sm dengan 30 sm dan dikekalkan pada suhu 60°C. Kirakan kadar pemindahan haba disebabkan perolakan semulajadi bagi suhu minyak pada 20°C.

[6 markah]

3. *[a] In order to test the principles of convection heat-transfer it is necessary to use Helium for the test at a pressure of 150 kPa and a temperature of 20°C flows across an area of 1.0 m^2 plate at a velocity of 50 m/s. The plate is maintained at a constant temperature of 100°C. Calculate the heat lost by the plate. (assuming that the length is equal to one meter).*

[5 marks]

[b] Ethylene glycol is to be cooled, for the test to be made for the convection heat-transfer, from 60 to 40°C in a 3 cm diameter tube. The tube wall temperature is maintained constant at 20°C. The glycol enters the tube with a velocity of 10 m/s. Calculate the length of the tube necessary for this forced cooling.

[5 marks]

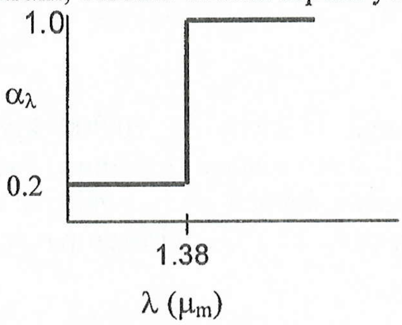
[c] An engine-oil heater consists of large vessel with a square plate electrical heater surface in the bottom of the vessel. The heater plate is 30 by 30 cm and is maintained at a constant temperature of 60°C. Calculate the natural convection heat-transfer rate due to natural convection for an oil temperature of 20°C.

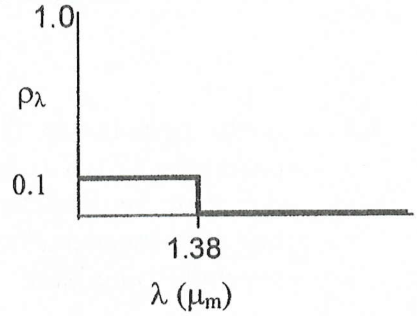
[6 marks]

...5/-

<u>Bahagian B</u> : Jawab mana-mana <u>DUA</u> soalan.
<u>Section B</u> : Answer any <u>TWO</u> questions.

4. Keberserapan spektrum, α_λ dan kepantulan spektrum, ρ_λ bagi bahan pilihan secara spektrum, berbaur adalah seperti yang ditunjukkan di bawah:





[a] Lakarkan spektrum kepindahan, τ_λ.

[5 markah]

[b] Sekiranya penyinaran suria dengan G_s = 750 W/m^2 dan taburan spektrum bagi badan hitam pada 5800 K melanggar bahan tersebut, kirakan pecahan-pecahan sinaran yang dipindah, dipantul dan diserap oleh bahan itu.

[8 markah]

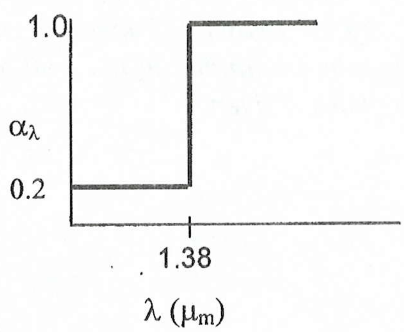
[c] Sekiranya suhu bahan itu ialah 350 K, kirakan keberpancaran, ε_λ.

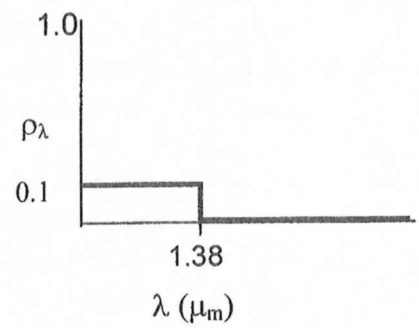
[7 markah]

[d] Tentukan fluks haba bersih penyinaran kepada bahan itu.

[5 markah]

4. *The spectral absorptivity, α_λ and spectral reflectivity, ρ_λ for a spectrally selective, diffuse material are shown below:*





[a] Sketch the spectral transmissivity, τ_λ.

[5 marks]

[b] If solar irradiation with G_s = 750 W/m^2 and the spectral distribution of a blackbody at 5800 K is incident on this material, determine the fractions of the irradiation that are transmitted, reflected and absorbed by the material.

[8 marks]

...6/-

[c] *If the temperature of this material is 350 K, determine the emissivity,* ε_λ.

[7 marks]

[d] *Determine the net heat flux by radiation to the material.*

[5 marks]

5. [a] Suatu pemeluwap direkabentuk untuk memeluwap 10,000 kg/jam bahan pendingin 12 (CCl_2F_2) pada 37.8°C. Suatu susunan segiempat sama 25 x 25, tiub yang berdiameter 12 mm digunakan dengan air mengalir ke dalam tiub-tiub bagi mengekalkan suhu dinding pada 32.2°C. Kirakan panjang tiub-tiub tersebut. Diberikan:

$h_{fg} = 130.09$ kJ/kg
$\rho = 1276$ kg/m^3
$\nu = 0.193 \times 10^{-6}$ m^2/s
$k = 0.07$ W/m . °C

[15 markah]

[b] Kirakan haba per unit panjang sekiranya bahan pendingin di bahagian [a] dipeluwap di dalam tiub melintang berdiameter 12 mm yang mempunyai halaju wap rendah. Suhu pemeluwapan ialah 32.3°C dan suhu dinding tiub ialah 26.7°C. Diberikan:

$h_{fg}' = h_{fg} + 0.68\, c\, \Delta T$.
di mana $c = 984$ J/kg°C

[10 markah]

5. *[a]* *A condenser is to be designed to condense 10,000 kg/hr of refrigerant 12 (CCl_2F_2) at 37.8°C. A square 25 by 25 array of 12 mm diameter tubes is to be used, with water flow inside the tubes maintaining the wall temperature at 32.2°C. Calculate the length of the tubes. Given:*

$h_{fg} = 130.09$ kJ/kg
$\rho = 1276$ kg/m^3
$\nu = 0.193 \times 10^{-6}$ m^2/s
$k = 0.07$ W/m . °C

[15 marks]

[b] *Calculate the heat per unit length if the refrigerant in part [a] is condensed inside a horizontal 12 mm diameter tube at a low vapor velocity. The condensing temperature is 32.3°C and the tube wall is at 26.7°C. Given:*

$h_{fg}' = h_{fg} + 0.68\, c\, \Delta T$.
where $c = 984$ J/kg°C

[10 marks]

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6. [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) di bawah syarat-syarat seperti di atas sekiranya U dikekalkan? Diberikan:

$h_{fg} = 2.255 \times 10^6$ J/kg

[15 markah]

6. *[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 U remains the same? Given :

$h_{fg} = 2.255 \times 10^6$ *J/kg*

[15 marks]

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Lampiran

Convection heat transfer equations

1. $Nu = 0.332\,(Pr)^{1/3}\,(Re)^{1/2}$

2. $Nu = 0.027\,(Re)^{0.8}\,(Pr)^{1/3}\,(\mu / \mu w)^{0.14}$

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

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

Grashof equation $Gr = g\ \beta\ (T_w - T_\infty)\,\delta^3 / \upsilon^2$

4. $K_e / K = C\,(Ra)^n\,(L / \delta)^m$ where $C = 0.13$ $n = 0.3$ $m = 0.0$
For any value of Ra

Air gas constant = 287 J /kg K
Universal gas constant = 8314.5 J/kg mol K
Helium Molecular wt. = 4

Table for Helium
Table for Ethylene glycol
Table for oil
Table for oxygen
Table for air

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Table Properties of gases at atmospheric pressure.†

Values of μ, k, c_p, and Pr are not strongly pressure-dependent for He, H_2, O_2, and N_2 and may be used over a fairly wide range of pressures

T, K	ρ kg/m³	c_p kJ/kg · °C	μ, kg/m · s	ν, m²/s	k W/m · °C	α, m²/s	Pr
			Helium				
144	0.3379	5.200	125.5 × 10⁻⁷	37.11 × 10⁻⁶	0.0928	0.5275 × 10⁻⁴	0.70
200	0.2435	5.200	156.6	64.38	0.1177	0.9288	0.694
255	0.1906	5.200	181.7	95.50	0.1357	1.3675	0.70
366	0.13280	5.200	230.5	173.6	0.1691	2.449	0.71
477	0.10204	5.200	275.0	269.3	0.197	3.716	0.72
589	0.08282	5.200	311.3	375.8	0.225	5.215	0.72
700	0.07032	5.200	347.5	494.2	0.251	6.661	0.72
800	0.06023	5.200	381.7	634.1	0.275	8.774	0.72
			Hydrogen				
150	0.16371	12.602	5.595 × 10⁻⁶	34.18 × 10⁻⁶	0.0981	0.475 × 10⁻⁴	0.718
200	0.12270	13.540	6.813	55.53	0.1282	0.772	0.719
250	0.09819	14.059	7.919	80.64	0.1561	1.130	0.713
300	0.08185	14.314	8.963	109.5	0.182	1.554	0.706
350	0.07016	14.436	9.954	141.9	0.206	2.031	0.697
400	0.06135	14.491	10.864	177.1	0.228	2.568	0.690
450	0.05462	14.499	11.779	215.6	0.251	3.164	0.682
500	0.04918	14.507	12.636	257.0	0.272	3.817	0.675
550	0.04469	14.532	13.475	301.6	0.292	4.516	0.668
600	0.04085	14.537	14.285	349.7	0.315	5.306	0.664
700	0.03492	14.574	15.89	455.1	0.351	6.903	0.659
800	0.03060	14.675	17.40	569	0.384	8.563	0.664
900	0.02723	14.821	18.78	690	0.412	10.217	0.676
			Oxygen				
150	2.6190	0.9178	11.490 × 10⁻⁶	4.387 × 10⁻⁶	0.01367	0.05688 × 10⁻⁴	0.773
200	1.9559	0.9131	14.850	7.593	0.01824	0.10214	0.745
250	1.5618	0.9157	17.87	11.45	0.02259	0.15794	0.725
300	1.3007	0.9203	20.63	15.86	0.02676	0.22353	0.709
350	1.1133	0.9291	23.16	20.80	0.03070	0.2968	0.702
400	0.9755	0.9420	25.54	26.18	0.03461	0.3768	0.695
450	0.8682	0.9567	27.77	31.99	0.03828	0.4609	0.694
500	0.7801	0.9722	29.91	38.34	0.04173	0.5502	0.697
550	0.7096	0.9881	31.97	45.05	0.04517	0.641	0.700
			Nitrogen				
200	1.7108	1.0429	12.947 × 10⁻⁶	7.568 × 10⁻⁶	0.01824	0.10224 × 10⁻⁴	0.747
300	1.1421	1.0408	17.84	15.63	0.02620	0.22044	0.713
400	0.8538	1.0459	21.98	25.74	0.03335	0.3734	0.691
500	0.6824	1.0555	25.70	37.66	0.03984	0.5530	0.684
600	0.5687	1.0756	29.11	51.19	0.04580	0.7486	0.686
700	0.4934	1.0969	32.13	65.13	0.05123	0.9466	0.691
800	0.4277	1.1225	34.84	81.46	0.05609	1.1685	0.700
900	0.3796	1.1464	37.49	91.06	0.06070	1.3946	0.711
1000	0.3412	1.1677	40.00	117.2	0.06475	1.6250	0.724
1100	0.3108	1.1857	42.28	136.0	0.06850	1.8571	0.736
1200	0.2851	1.2037	44.50	156.1	0.07184	2.0932	0.748

Table Properties of gases at atmospheric pressure.[†] (*Continued*)

Values of μ, k, c_p, and Pr are not strongly pressure-dependent for He, H_2, O_2, and N_2 and may be used over a fairly wide range of pressures

T, K	ρ kg/m³	c_p kJ/kg·°C	μ, kg/m·s	v, m²/s	k W/m·°C	α, m²/s	Pr
			Carbon dioxide				
220	2.4733	0.783	11.105×10^{-6}	4.490×10^{-6}	0.010805	0.05920×10^{-4}	0.818
250	2.1657	0.804	12.590	5.813	0.012884	0.07401	0.793
300	1.7973	0.871	14.958	8.321	0.016572	0.10588	0.770
350	1.5362	0.900	17.205	11.19	0.02047	0.14808	0.755
400	1.3424	0.942	19.32	14.39	0.02461	0.19463	0.738
450	1.1918	0.980	21.34	17.90	0.02897	0.24813	0.721
500	1.0732	1.013	23.26	21.67	0.03352	0.3084	0.702
550	0.9739	1.047	25.08	25.74	0.03821	0.3750	0.685
600	0.8938	1.076	26.83	30.02	0.04311	0.4483	0.668
			Ammonia, NH_3				
273	0.7929	2.177	9.353×10^{-6}	1.18×10^{-5}	0.0220	0.1308×10^{-4}	0.90
323	0.6487	2.177	11.035	1.70	0.0270	0.1920	0.88
373	0.5590	2.236	12.886	2.30	0.0327	0.2619	0.87
423	0.4934	2.315	14.672	2.97	0.0391	0.3432	0.87
473	0.4405	2.395	16.49	3.74	0.0467	0.4421	0.84
			Water vapor				
380	0.5863	2.060	12.71×10^{-6}	2.16×10^{-5}	0.0246	0.2036×10^{-4}	1.060
400	0.5542	2.014	13.44	2.42	0.0261	0.2338	1.040
450	0.4902	1.980	15.25	3.11	0.0299	0.307	1.010
500	0.4405	1.985	17.04	3.86	0.0339	0.387	0.996
550	0.4005	1.997	18.84	4.70	0.0379	0.475	0.991
600	0.3652	2.026	20.67	5.66	0.0422	0.573	0.986
650	0.3380	2.056	22.47	6.64	0.0464	0.666	0.995
700	0.3140	2.085	24.26	7.72	0.0505	0.772	1.000
750	0.2931	2.119	26.04	8.88	0.0549	0.883	1.005
800	0.2739	2.152	27.86	10.20	0.0592	1.001	1.010
850	0.2579	2.186	29.69	11.52	0.0637	1.130	1.019

[†]Adapted to SI units from E. R. G. Eckert and R. M. Drake, *Heat and Mass Transfer*, 2nd ed. New York: McGraw-Hill, 1959.

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Table Properties of saturated liquids.[†]

T, °C	ρ kg/m^3	c_p kJ/kg·°C	ν, m^2/s	k W/m·°C	α, m^2/s	Pr	β, K^{-1}
Ammonia, NH_3							
−50	703.69	4.463	0.435 × 10^{-6}	0.547	1.742 × 10^{-7}	2.60	
−40	691.68	4.467	0.406	0.547	1.775	2.28	
−30	679.34	4.476	0.387	0.549	1.801	2.15	
−20	666.69	4.509	0.381	0.547	1.819	2.09	
−10	653.55	4.564	0.378	0.543	1.825	2.07	
0	640.10	4.635	0.373	0.540	1.819	2.05	
10	626.16	4.714	0.368	0.531	1.801	2.04	
20	611.75	4.798	0.359	0.521	1.775	2.02	2.45 × 10^{-3}
30	596.37	4.890	0.349	0.507	1.742	2.01	
40	580.99	4.999	0.340	0.493	1.701	2.00	
50	564.33	5.116	0.330	0.476	1.654	1.99	
Carbon dioxide, CO_2							
−50	1,156.34	1.84	0.119 × 10^{-6}	0.0855	0.4021 × 10^{-7}	2.96	
−40	1,117.77	1.88	0.118	0.1011	0.4810	2.46	
−30	1,076.76	1.97	0.117	0.1116	0.5272	2.22	
−20	1,032.39	2.05	0.115	0.1151	0.5445	2.12	
−10	983.38	2.18	0.113	0.1099	0.5133	2.20	
0	926.99	2.47	0.108	0.1045	0.4578	2.38	
10	860.03	3.14	0.101	0.0971	0.3608	2.80	
20	772.57	5.0	0.091	0.0872	0.2219	4.10	14.00 × 10^{-3}
30	597.81	36.4	0.080	0.0703	0.0279	28.7	
Sulfur dioxide, SO_2							
−50	1,560.84	1.3595	0.484 × 10^{-6}	0.242	1.141 × 10^{-7}	4.24	
−40	1,536.81	1.3607	0.424	0.235	1.130	3.74	
−30	1,520.64	1.3616	0.371	0.230	1.117	3.31	
−20	1,488.60	1.3624	0.324	0.225	1.107	2.93	
−10	1,463.61	1.3628	0.288	0.218	1.097	2.62	
0	1,438.46	1.3636	0.257	0.211	1.081	2.38	
10	1,412.51	1.3645	0.232	0.204	1.066	2.18	
20	1,386.40	1.3653	0.210	0.199	1.050	2.00	1.94 × 10^{-3}
30	1,359.33	1.3662	0.190	0.192	1.035	1.83	
40	1,329.22	1.3674	0.173	0.185	1.019	1.70	
50	1,299.10	1.3683	0.162	0.177	0.999	1.61	
Dichlorodifluoromethane (Freon-12), CCl_2F_2							
−50	1,546.75	0.8750	0.310 × 10^{-6}	0.067	0.501 × 10^{-7}	6.2	2.63 × 10^{-3}
−40	1,518.71	0.8847	0.279	0.069	0.514	5.4	
−30	1,489.56	0.8956	0.253	0.069	0.526	4.8	
−20	1,460.57	0.9073	0.235	0.071	0.539	4.4	
−10	1,429.49	0.9203	0.221	0.073	0.550	4.0	
0	1,397.45	0.9345	0.214 × 10^{-6}	0.073	0.557 × 10^{-7}	3.8	
10	1,364.30	0.9496	0.203	0.073	0.560	3.6	
20	1,330.18	0.9659	0.198	0.073	0.560	3.5	
30	1,295.10	0.9835	0.194	0.071	0.560	3.5	
40	1,257.13	1.0019	0.191	0.069	0.555	3.5	
50	1,215.96	1.0216	0.190	0.067	0.545	3.5	

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Table Properties of saturated liquids[†] (*Continued*).

T, °C	ρ kg/m³	c_p kJ/kg·°C	ν, m²/s	k W/m·°C	α, m²/s	Pr	β, K⁻¹
			Glycerin, $C_3H_5(OH)_3$				
0	1,276.03	2.261	0.00831	0.282	0.983×10^{-7}	84.7×10^3	0.50×10^{-3}
10	1,270.11	2.319	0.00300	0.284	0.965	31.0	
20	1,264.02	2.386	0.00118	0.286	0.947	12.5	
30	1,258.09	2.445	0.00050	0.286	0.929	5.38	
40	1,252.01	2.512	0.00022	0.286	0.914	2.45	
50	1,244.96	2.583	0.00015	0.287	0.893	1.63	
			Ethylene glycol, $C_2H_4(OH)_2$				
0	1,130.75	2.294	7.53×10^{-6}	0.242	0.934×10^{-7}	615	0.65×10^{-3}
20	1,116.65	2.382	19.18	0.249	0.939	204	
40	1,101.43	2.474	8.69	0.256	0.939	93	
60	1,087.66	2.562	4.75	0.260	0.932	51	
80	1,077.56	2.650	2.98	0.261	0.921	32.4	
100	1,058.50	2.742	2.03	0.263	0.908	22.4	
			Engine oil (unused)				
0	899.12	1.796	0.00428	0.147	0.911×10^{-7}	47,100	0.70×10^{-3}
20	888.23	1.880	0.00090	0.145	0.872	10,400	
40	876.05	1.964	0.00024	0.144	0.834	2,870	
60	864.04	2.047	0.839×10^{-4}	0.140	0.800	1,050	
80	852.02	2.131	0.375	0.138	0.769	490	
100	840.01	2.219	0.203	0.137	0.738	276	
120	828.96	2.307	0.124	0.135	0.710	175	
140	816.94	2.395	0.080	0.133	0.686	116	
160	805.89	2.483	0.056	0.132	0.663	84	
			Mercury, Hg				
0	13,628.22	0.1403	0.124×10^{-6}	8.20	42.99×10^{-7}	0.0288	1.82×10^{-4}
20	13,579.04	0.1394	0.114	8.69	46.06	0.0249	
50	13,505.84	0.1386	0.104	9.40	50.22	0.0207	
100	13,384.58	0.1373	0.0928	10.51	57.16	0.0162	
150	13,264.28	0.1365	0.0853	11.49	63.54	0.0134	
200	13,144.94	0.1570	0.0802	12.34	69.08	0.0116	
250	13,025.60	0.1357	0.0765	13.07	74.06	0.0103	
315.5	12,847	0.134	0.0673	14.02	81.5	0.0083	

[†]Adapted to SI units from E. R. G. Eckert and R. M. Drake. *Heat and Mass Transfer*, 2d ed. New York: McGraw-Hill, 1959.

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Table 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 · °C	$\mu \times 10^5$ kg/m · s	$\nu \times 10^6$ m^2/s	k W/m · °C	$\alpha \times 10^4$ 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
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

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Table Heat-exchanger effectiveness relations.

$N = \text{NTU} = \dfrac{UA}{C_{min}}$ $C = \dfrac{C_{min}}{C_{max}}$

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

Table NTU relations for heat exchangers.

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

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

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Equations	$E_{b_{0-\infty}} = \sigma T^4$ $E_{b\lambda} = \dfrac{C_1 \lambda^{-5}}{e^{C_2/\lambda T} - 1}$ $\lambda_{\max} T = C_3$ $\mathrm{Re} = \dfrac{4\dot{m}}{\mu_l b}$
Laminar condensation on a vertical plate $(\mathrm{Re} < 30)$	$\delta(x) = \left[\dfrac{4k_l \mu_l (T_{sat} - T_s)x}{g\rho_l(\rho_l - \rho_v)h_{fg}}\right]^{1/4}$ $\bar{h} = 0.943\left[\dfrac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{\mu_l(T_{sat} - T_s)L}\right]^{1/4}$
Laminar-wavy condensation $(30 \le \mathrm{Re} \le 1800)$	$\dfrac{\bar{h}(v^2/g)^{1/3}}{k_l} = \dfrac{\mathrm{Re}}{1.08\,\mathrm{Re}^{1.22} - 5.2}$
Laminar film condensation on **vertical tube**	$\bar{h} = 0.729\left[\dfrac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{N\mu_l(T_{sat} - T_s)D}\right]^{1/4}$
Laminar film condensation on **horizontal tube**	$\bar{h} = 0.555\left[\dfrac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{N\mu_l(T_{sat} - T_s)D}\right]^{1/4}$
For turbulent film condensation $(\mathrm{Re} \ge 1800)$	$\dfrac{\bar{h}(v^2/g)^{1/3}}{k_l} = \dfrac{\mathrm{Re}}{8750 + 58\,\mathrm{Pr}^{-0.5}(\mathrm{Re}^{0.75} - 253)}$

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Table Radiation function

λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2 K^5 \mu m \times 10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$	λT μmK	$E_{b\lambda}/T^5$ $\frac{W}{m^2 K^5 \mu m \times 10^{11}}$	$\frac{E_{b0-\lambda T}}{\sigma T^4}$
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

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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

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