UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2004/2005

Mac 2005

EKC 213 – Pemindahan Haba Proses

Masa : 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN muka surat yang bercetak dan EMPAT BELAS muka surat Lampiran sebelum anda memulakan peperiksaan ini.

Arahan: Jawab **EMPAT (4)** soalan. Jawab mana-mana **DUA (2)** 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.

Bahagian A : Jawab mana-mana DUA soalan.
Section A : Answer any TWO questions.

1. [a] Terbitkan satu ungkapan bagi fluks haba melalui kelompang sfera geronggang yang mempunyai radius dalaman r_i dan radius luaran r_o serta mempunyai keberaliran haba, K.

[6 markah]

[b] Sebuah kontena logam berbentuk sfera dan mempunyai dinding nipis digunakan untuk menyimpan nitrogen cecair pada 77 K. Kontena tersebut mempunyai garispusat 0.5 m dan diselaputi dengan penebat diperbuat daripada serbuk silika. Penebat tersebut berketebalan 25 mm dan permukaan luar didedahkan kepada udara ambien pada 300 K. Pekali perosakan adalah 20 $W/m^2.K$. Haba pendam pengewapan dan ketumpatan nitrogen cecair masing-masing pada 2×10^5 J/kg dan 0.804 kg/m^3. Keberaliran haba bagi serbuk silika pada 300 K adalah 0.0017 W/m.K.

[i] Apakah kadar pemindahan haba kepada nitrogen cecair?

[7 markah]

[ii] Apakah kadar didih-habis cecair (atau kehilangan) di dalam liter per hari?

[4 markah]

[iii] Kirakan suhu dalaman dan luaran pada permukaan penebat tersebut.

[8 markah]

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

[6 marks]

[b] A spherical, thin-walled metallic container is used to store liquid nitrogen at 77 K. The container has a diameter of 0.5 m and is covered with an insulation composed of silica powder. The insulation is 25 mm thick and its outer surface is exposed to ambient air at 300 K. The convection coefficient is known to be 20 $W/m^2.K$. The latent heat of vaporization and the density of liquid nitrogen are 2×10^5 J/kg and 0.804 kg/m^3, respectively. The thermal conductivity for the silica powder at 300 K is 0.0017 W/m.K.

[i] What is the rate of heat transfer to the liquid nitrogen?

[7 marks]

[ii] What is the rate of liquid boil-off (or lost) in liters per day?

[4 marks]

[iii] Calculate the temperature of the inside and outside surfaces of the insulation.

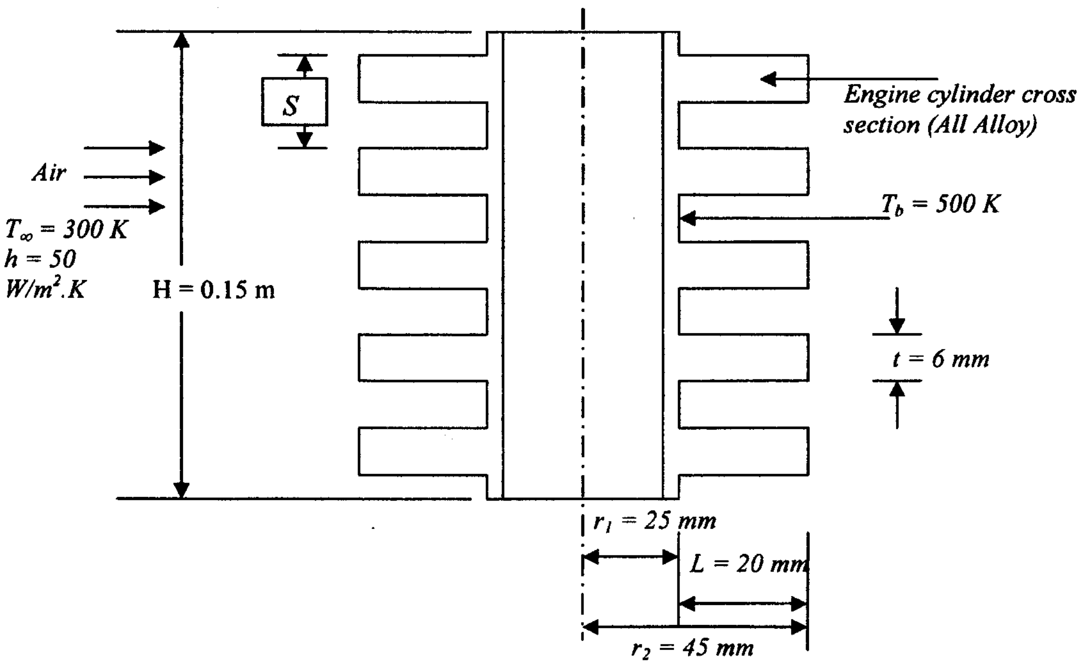
[8 marks]

2. Enjin silinder sebuah pam air dibina menggunakan aloi aluminium dan mempunyai ketinggian H = 0.15 m dan garispusat luaran D = 50 mm seperti yang ditunjukkan dalam Rajah S.2.1 di bawah. Di bawah keadaan pengendalian yang lazim, permukaan luaran silinder adalah pada suhu 500 K dan didedahkan pada udara ambien pada 300 K, dengan pekali perolakan 50 W/m^2.K. Sirip anulus diintegrasikan bersama silinder untuk meningkatkan pemindahan haba ke persekitaran. Pertimbangkan lima sirip seperti itu yang mempunyai ketebalan t = 6 mm, panjang L = 20 mm dan ditempatkan secara saksama. Keberaliran haba untuk aloi aluminium pada 400 K adalah 186 W/m.K.

[a] Kirakan pemindahan haba di dalam sistem

[8 markah]

[b] Kirakan pemindahan haba bagi silinder dengan sirip dan tanpa sirip tersebut dan tentukan peningkatan pemindahan haba.
[Kecekapan sirip diberikan di dalam Rajah S.2.2 di Lampiran A]



Rajah S.2.1 Enjin Silinder

[4 markah]

[c] Kirakan bilangan sirip yang diperlukan untuk keadaan yang sama seperti di atas jika pemindahan haba yang diperlukan adalah 1400 W.

[13 markah]

2. *The engine cylinder of a water pump is constructed of aluminum alloy and is of height $H = 0.15$ m and outside diameter $D = 50$ mm as shown in Figure Q.2.1. below. Under typical operating conditions, the outer surface of the cylinder is at temperature of 500 K and is exposed to ambient air at 300 K, with a convection coefficient of 50 W/m^2.K. Annular fins are integrally cast with the cylinder to increase heat transfer to the surroundings. Consider five such fins, which are of thickness $t = 6$ mm, length $L = 20$ mm and equally spaced. Thermal conductivity for the aluminum alloy at 400 K is 186 W/m.K.*

[a] *Calculate the heat transfer in the system*

[8 marks]

[b] *Calculate the heat transfer for a cylinder with and without the fins and determine the improvement in heat transfer.*
[Fin efficiency is given in Figure Q.2.2 (Appendix)]

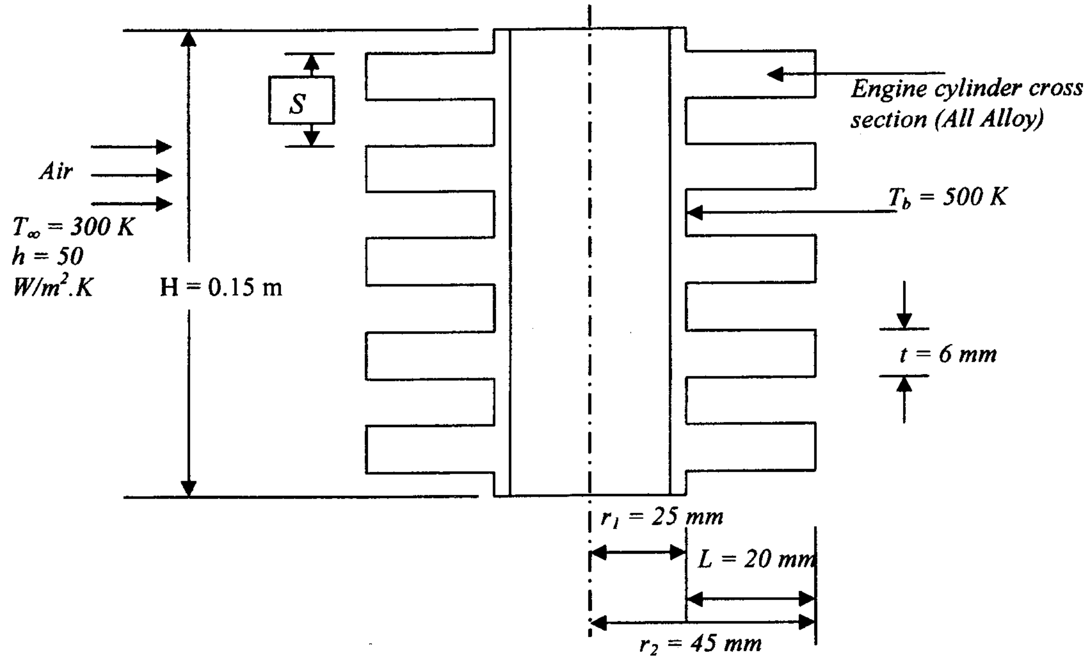


Figure Q.2.1

[4 marks]

[c] *Calculate the number of fins required for the same condition above if the heat transfer required is 1400 W.*

[13 marks]

3. Satu kumpulan tiub mengandungi 144 tiub bertatasusunan segi empat sama diatur di dalam kedudukan sebaris. Setiap tiub mempunyai garispusat 1.5 sm dan panjang 1.0 m; jarak pusat ke pusat tiub adalah 2.0 sm. Suhu permukaan tiub disenggarakan pada 350 K dan udara memasuki kumpulan tiub tersebut pada 1 bar, 300 K dan kelajuan udara (U∞ = 6 m/s)

[a] Kirakan suhu udara keluar dan pekali pemindahan haba.

[6 markah]

[b] Kirakan jumlah kehilangan haba oleh kesemua tiub.

[6 markah]

[c] Kirakan jumlah haba yang hilang oleh kesemua tiub bagi keadaan yang sama sekiranya kelajuan udara U_∞ = 11.0 m/s

[Diberi Jadual S.3.1 dan S.3.2 di dalam Lampiran B untuk data]

[13 markah]

3. *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 centre-to-centre tube spacing is 2.0 cm. The surface temperature of the tubes is maintained at 350 K and air enters the tube bank at 1 bar, 300 K and the air speed (U_∞ = 6 m/s)*

[a] Calculate exit air temperature and heat transfer coefficient

[6 marks]

[b] Calculate the total heat lost by the tubes

[6 marks]

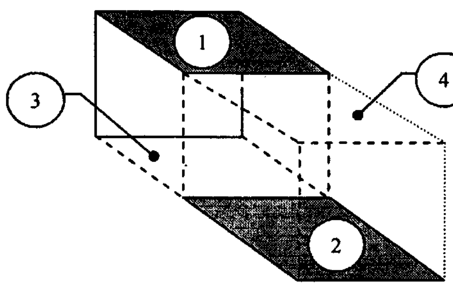
[c] Calculate the total heat lost by the tubes for the same condition if the air speed U_∞ = 11.0 m/s

[Use Table Q.3.1 and Q.3.2 in the Appendix B for data]

[13 marks]

Bahagian B : Jawab mana-mana DUA soalan.
Section B : Answer any TWO questions.

4. [a] Dapatkan ungkapan bagi faktor pandangan F_{12}



Data yang berkaitan diberi dalam Gambarajah 4.1 hingga 4.5 di Lampiran C.

[7 markah]

[b] Bendalir kriogenik mengalir melalui tiub bergarispusat 20 mm. Permukaan luarannya adalah berselerak-kelabu mempunyai keberpancaran 0.02 dan suhu 77 K. Tiub ini adalah sepusat dengan tiub yang lebih besar yang bergarispusat 50 mm, permukaan dalamannya adalah berselerak-kelabu mempunyai keberpancaran 0.05 dan suhu 300 K. Ruang di antara permukaan-permukaan dikosongkan. Kirakan haba yang diperolehi oleh bendalir kriogenik per unit panjang di dalam tiub dalaman.

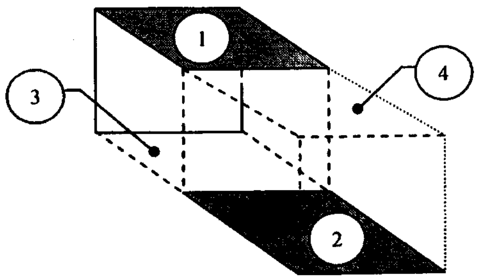
[10 markah]

[c] Sekiranya pelindung sinaran berdinding nipis yang berselerak-kelabu yang mempunyai keberpancaran 0.02 (kedua-dua bahagian) dimasukkan di antara permukaan dalaman dan luaran, kirakan perbezaan (peratus) haba yang diperolehi per unit panjang di dalam tiub dalaman.

[Data diberi dalam Jadual 4 – 6 seperti di Lampiran C]

[8 markah]

4. *[a]* *Obtain expression for the view factor F_{12}*



Relevant Data are given in Figure 4.1 to 4.5 in the Appendix C.

[7 marks]

[b] *A cryogenic fluid flows through a tube of 20 mm diameter. The outer surface of which is diffuse-gray with an emisivity of 0.02 and temperature of 77 K. This tube is concentric with a larger tube of 50 mm diameter, the inner surface of which is diffuse-gray with an emissivity of 0.05 and temperature of 300 K. The space between the surfaces is evacuated. Calculate the heat gain by the cryogenic fluid per unit length of the inner tube.*

[10 marks]

[c] *If a thin-walled radiation shield that is diffuse-gray with an emissivity of 0.02 (both sides) is inserted between the inner and other surfaces, calculate the change (percentage) in heat gain per unit length of the inner tube.*

[Data given in Table 4 – 6 in the Appendix C]

[8 marks]

5. [a] Stim tepu pada 1.5 bar memeluwap di dalam paip bergarispusat, 75 mm yang melintang. Permukaannya dikekalkan pada suhu 100°C. Andaikan pemeluwapan filem halaju wap rendah berlaku, anggarkan pekali pemindahan haba dan kadar pemeluwapan per unit panjang paip.

Diberikan :

Sifat-sifat bagi stim terdapat dalam Jadual S.5 [a] dalam Lampiran D.
h_{fs} = 2244 kJ/kg

[12 markah]

[b] Suatu pemeluwap direkabentuk untuk memeluwapkan 1,000 kg/jam bahan pendingin Freon-12 (CCl_2F) pada 37.8°C. Tiub-tiub yang bergarispusat 12.5 mm di dalam tatasusunan segiempat sama 25 kali 25 digunakan, dengan air dialirkan ke dalam tiub dan suhu dinding pada 32.2°C. Kirakan panjang tiub-tiub berkenaan.

Diberikan:

h_{fg} = 130 KJ/kg. T_f = 35°C, ρ_f = 1276 kg/m^3, ν = 0.193 x 10^{-6}m^2/s,
k_f = 0.07 W/m.K

[13 markah]

5. *[a]* *Saturated steam at 1.5 bar condenses inside a horizontal, 75 mm diameter pipe. The surface is maintained at 100°C. Assuming low vapor velocities film condensation occurs, estimate the heat transfer coefficient and condensation rate per unit length of the pipe.*

Given :

properties of steam in Table Q.5 [a] in the Appendix D.
h_{fs} = *2244 kJ/kg*

[12 marks]

[b] *A condenser is to be designed to condense 1,000 kg/h of refrigerant Freon-12 (CCl_2F) at 37.8°C. A square 25 by array of 12.5 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 KJ/kg.* T_f = *35°C,* ρ_f = *1276 kg/m^3,* ν = *0.193 x 10^{-6}m^2/s,*
k_f = *0.07 W/m.K*

[13 marks]

6. [a] Sebuah pemeluwap stim kelompang dan tiub dibina dengan menggunakan 2.5 sm OD, 2.2 sm ID, dan satu laluan tiub mendatar. Stim memeluwap di luar tiub pada suhu T_s = 54°C. Air sejuk mengalir masuk ke dalam setiap tiub pada suhu T_i = 18°C, dengan kadar aliran 0.7 kg/s per tiub. Air sejuk mengalir keluar pada suhu T_o = 36°C. Pekali pemindahan haba bagi pemeluwapan stim adalah h_s = 8000 W/m^{2}K. Kira kadar pemindahan haba, Q dan panjang tiub L. Gunakan kaedah,

[i] LMTD

[ii] E-NTU

[10 markah]

Data diberi :

Persamaan Dittus-Boelter : $Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$
(digunakan untuk mengira pekali pemindahan haba bagi bahagian air)
Sifat fizikal air pada suhu 27°C
Cp = 4180 J/kg°C $\quad$ μ = 0.86 x 10^{-3} kg/ms
Pr = 5.9 $\quad$ k = 0.61 W/m.K

[Data diberi dalam Gambarajah S.6.1 seperti di Lampiran E]

[b] Gas ekzos panas pada suhu 300°C yang mengalir masuk ke dalam sebuah penukar haba tiub bersirip beraliran silang dan keluar pada suhu 100°C. Penukar haba tersebut digunakan untuk memanaskan air bertekanan yang berkadar aliran 1 kg/s, daripada suhu 35°C kepada 125°C. Nilai haba tentu gas ekzos adalah 1000 J/kg K dan pekali pemindahan haba keseluruhan adalah 100 W/m^2 K. Kirakan luas permukaan pemindahan haba dengan menggunakan kaedah:

[i] E-NTU

[ii] LMTD

Data diberi : C_{Pw} = 4197 J/kg K

[Carta yang diperlukan di Gambarajah S.6.1 seperti di Lampiran E]

[15 markah]

6. *[a] A shell and tube steam condenser is to be constructed of 2.5 cm OD, 2.2 cm ID, single pass horizontal tube with steam condensing outside the tubes has a surface temperature T_s = 54°C. The cooling water enters each tube at T_i = 18°C, with a flowrate of 0.7 kg/s per tube and leaves at T_o = 36°C. The heat transfer coefficient for the condensation of steam is h_s = 8000 W/m^{2}K. Calculate the heat transfer rate, Q and the tube length L using.*

[i] LMTD method

[ii] E-NTU method

[10 marks]

Data given :

Dittus-Boelter equation : $Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$
(used to determine the heat transfer coefficient for the water side)
Physical properties of water taken at 27°C
Cp = 4180 J/kg°C *$\mu = 0.86 \times 10^{-3}$ kg/ms*
Pr = 5.9 *k = 0.61 W/m.K*

[Data given in Figure Q.6.1 in the Appendix E]

[b] Hot exhaust gases which enter a finned tube cross-flow heat exchanger at 300°C and leave at 100°C are used to heat pressurized water at a flowrate of 1 kg/s, from 35°C to 125°C. The exhaust gas specific heat is 1000 J/kg K and overall heat transfer coefficient is 100 W/m^2 K. Calculate the gas side surface area using the

[i] E-NTU method

[ii] LMTD method

Data given : C_{Pw} = 4197 J/kg K

[The relevant charts are shown in Figure Q.6.1 in the Appendix E]

[15 marks]

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Lampiran A

1. Heat transfer equation for fins corresponding to figures ($Q_2 - 1$) and ($Q_2 - 2$).

$$q_t = h A_t (T_b - T_\infty)\left[1 - N\frac{A_f}{A_t}(1-\eta_f)\right]$$

where $A_f = 2\pi\left(r_{2c}^2 - r_1^2\right)$

$A_t = N A_f + 2\pi r_1 (H - Nt)$

2. Heat transfer equation for tube bank corresponding to table ($Q_3 - 2$)

$$Nu = \frac{hd}{K} = C(R_n)^n (Pr)^{\frac{1}{3}}$$

Gas constant (R) 8.314 kJ/kmol.K
Molecular weight of Air = 29.92

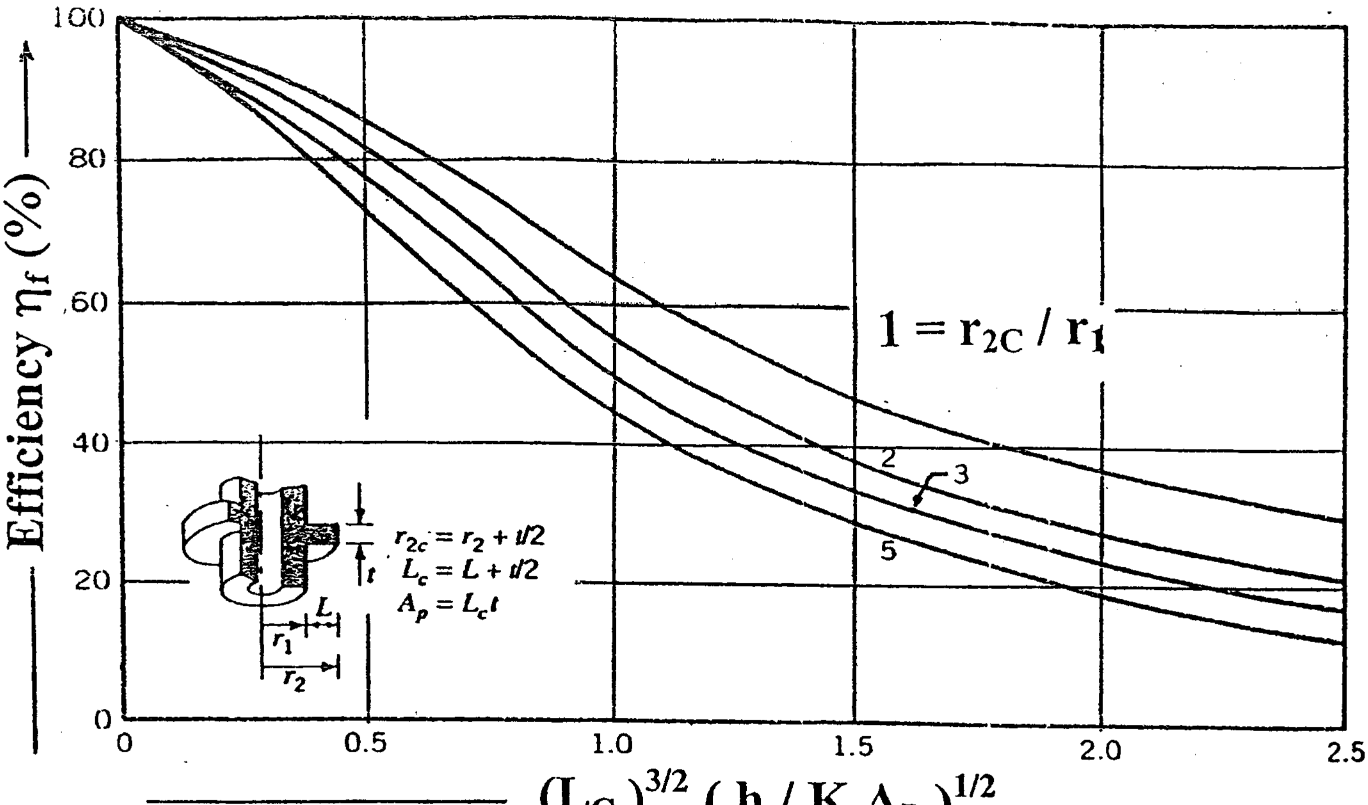


Figure Q.2.2 Efficiency of annular fins of rectangular profile

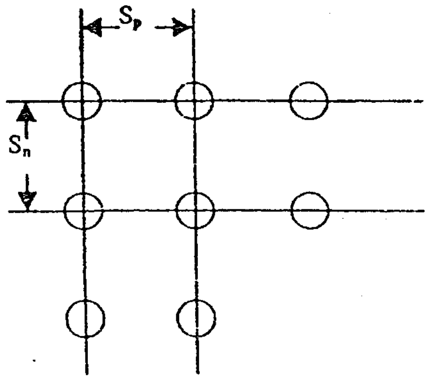
Lampiran B

Table Q. 3.1 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/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

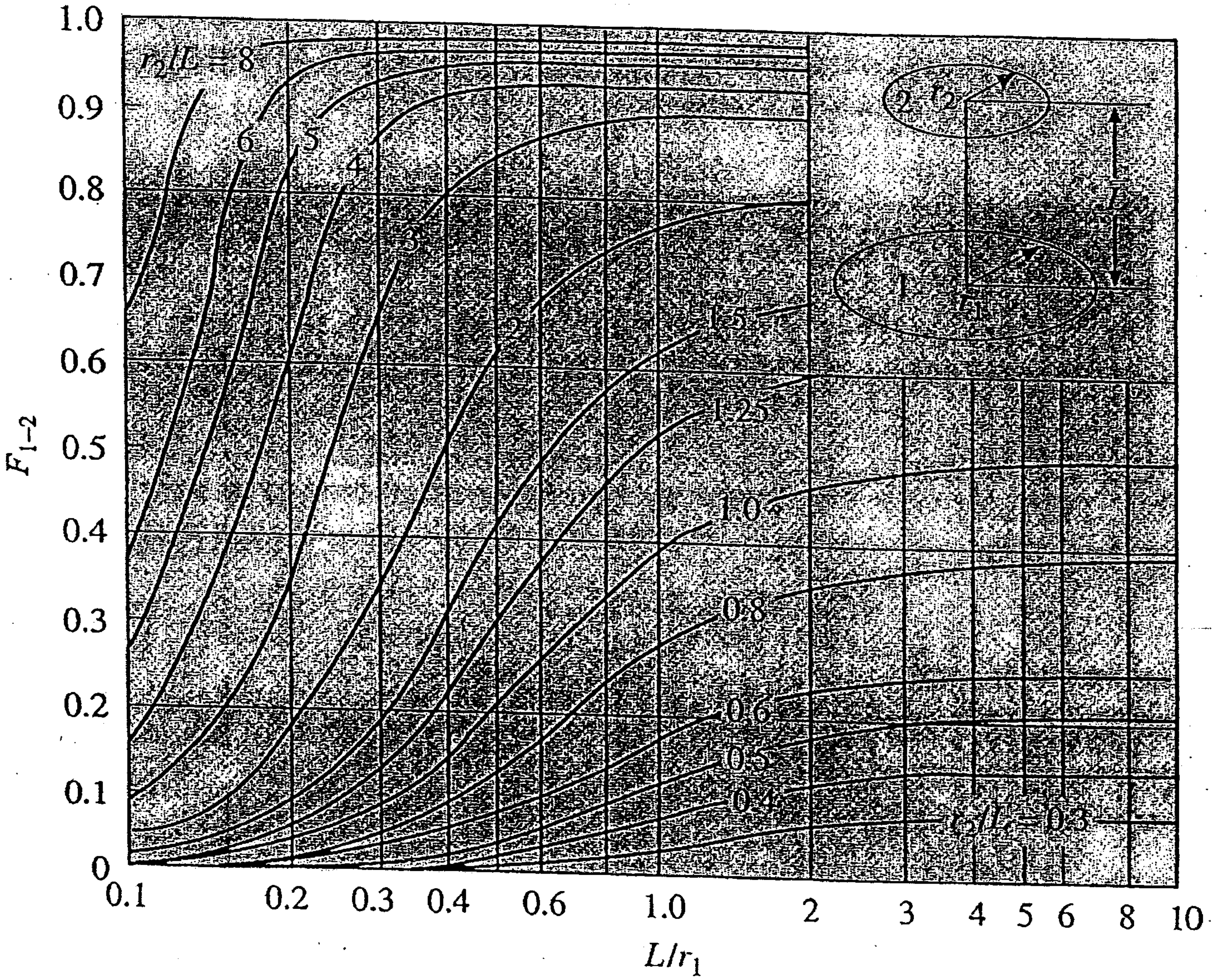
Table Q.3.2 Correlation of Grimson to Heat Transfer in Tube Banks of 10 Rows or More.

$\frac{S_p}{d}$	$\frac{S_n}{d}$ = 1.25		1.5		2.0		3.0	
	C	n	C	n	C	n	C	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	0.601	0.601	0.396	0.584	0.415	0.581	0.317	0.608



Lampiran C

Figure 4.1 Radiation shape factor for radiation between two parallel coaxial disks.



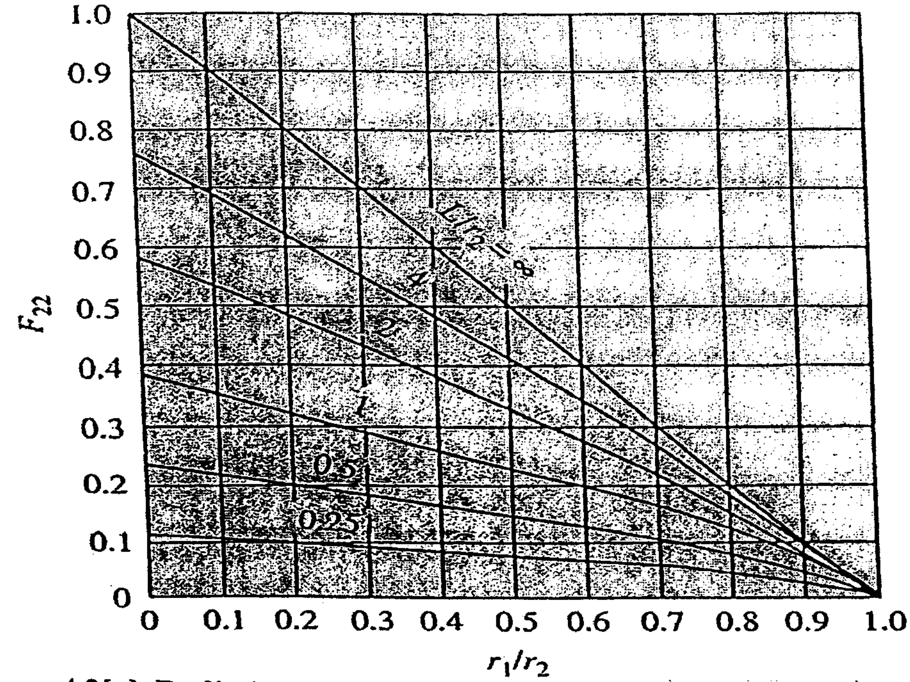


Figure 4.2[a] Radiation shape factors for two concentric cylinders of finite length. (*a*) Outer cylinder to itself; (*b*) Outer cylinder to inner cylinder.

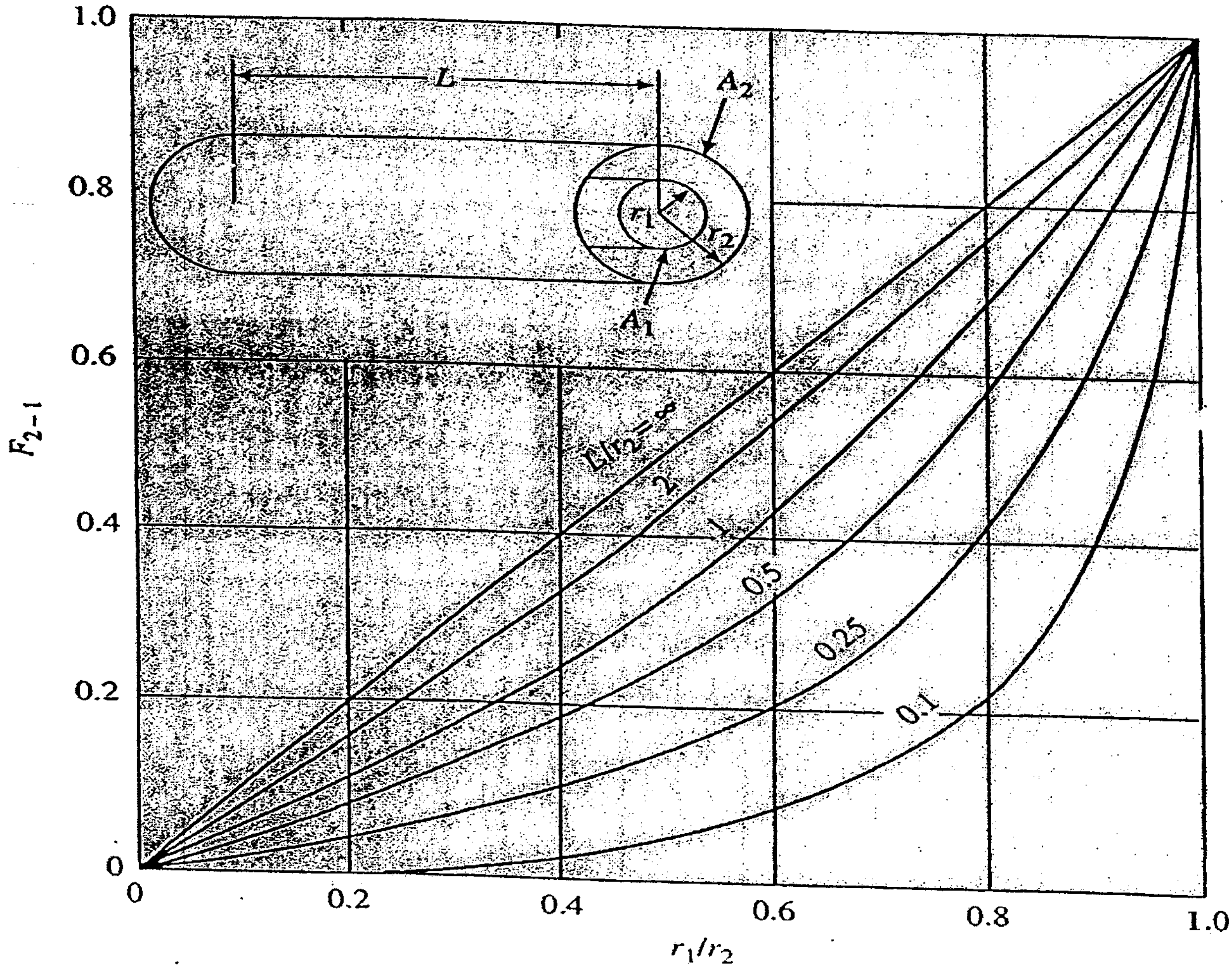


Figure 4.2.[b]

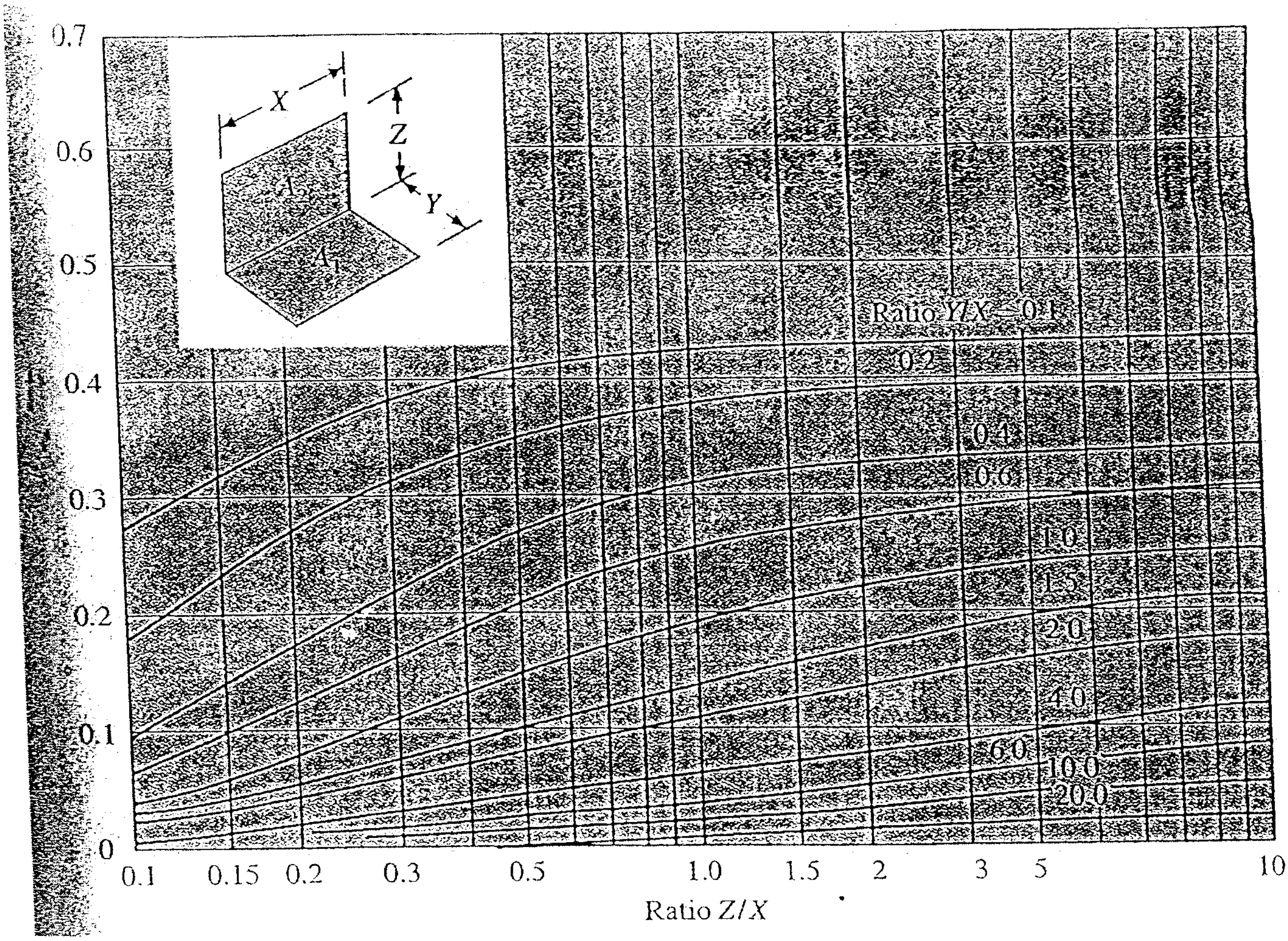


Figure 4.3 Radiation shape factor for radiation between perpendicular rectangles with a common edge.

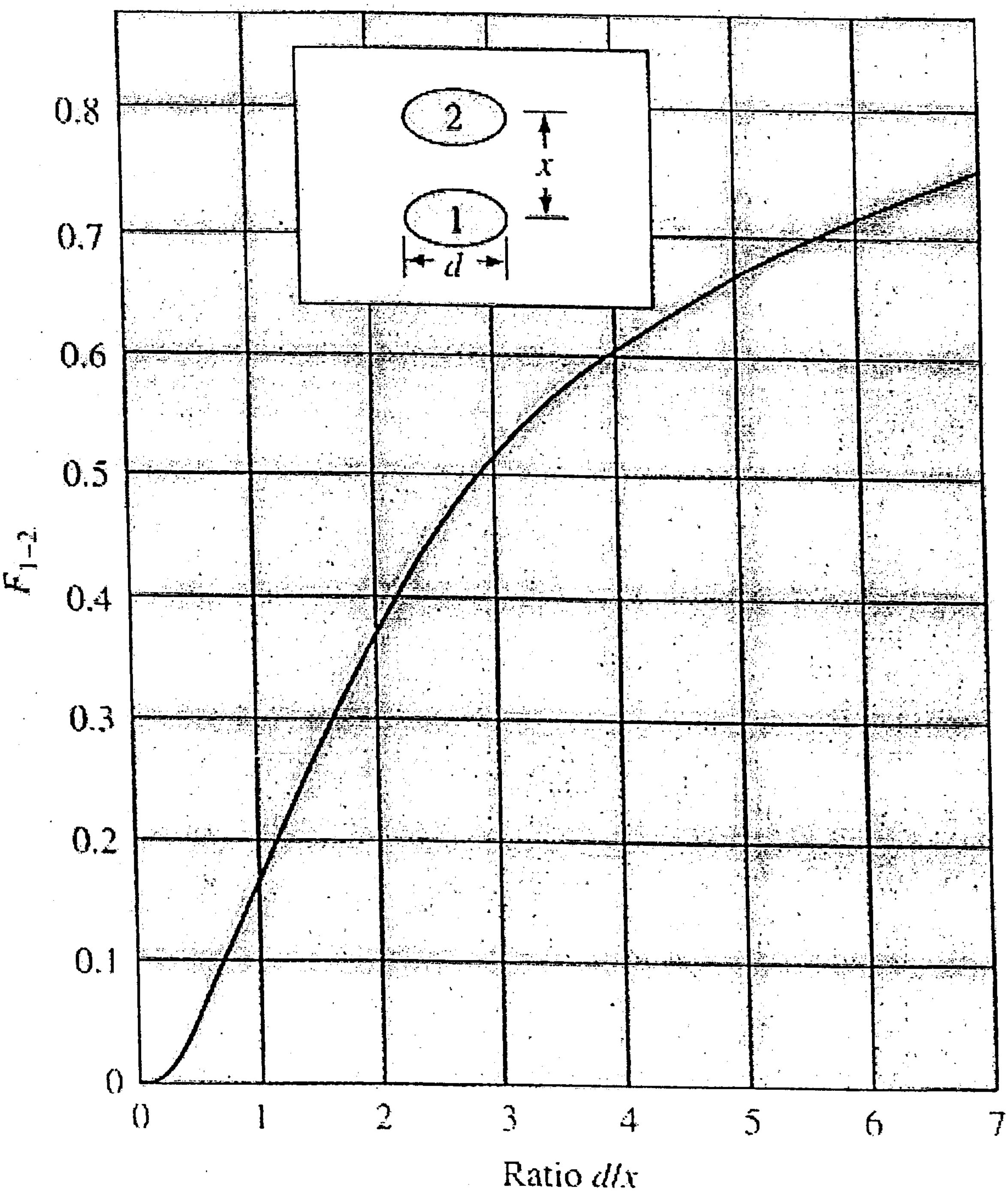


Figure 4.4 Radiation shape factor for radiation between parallel disks.

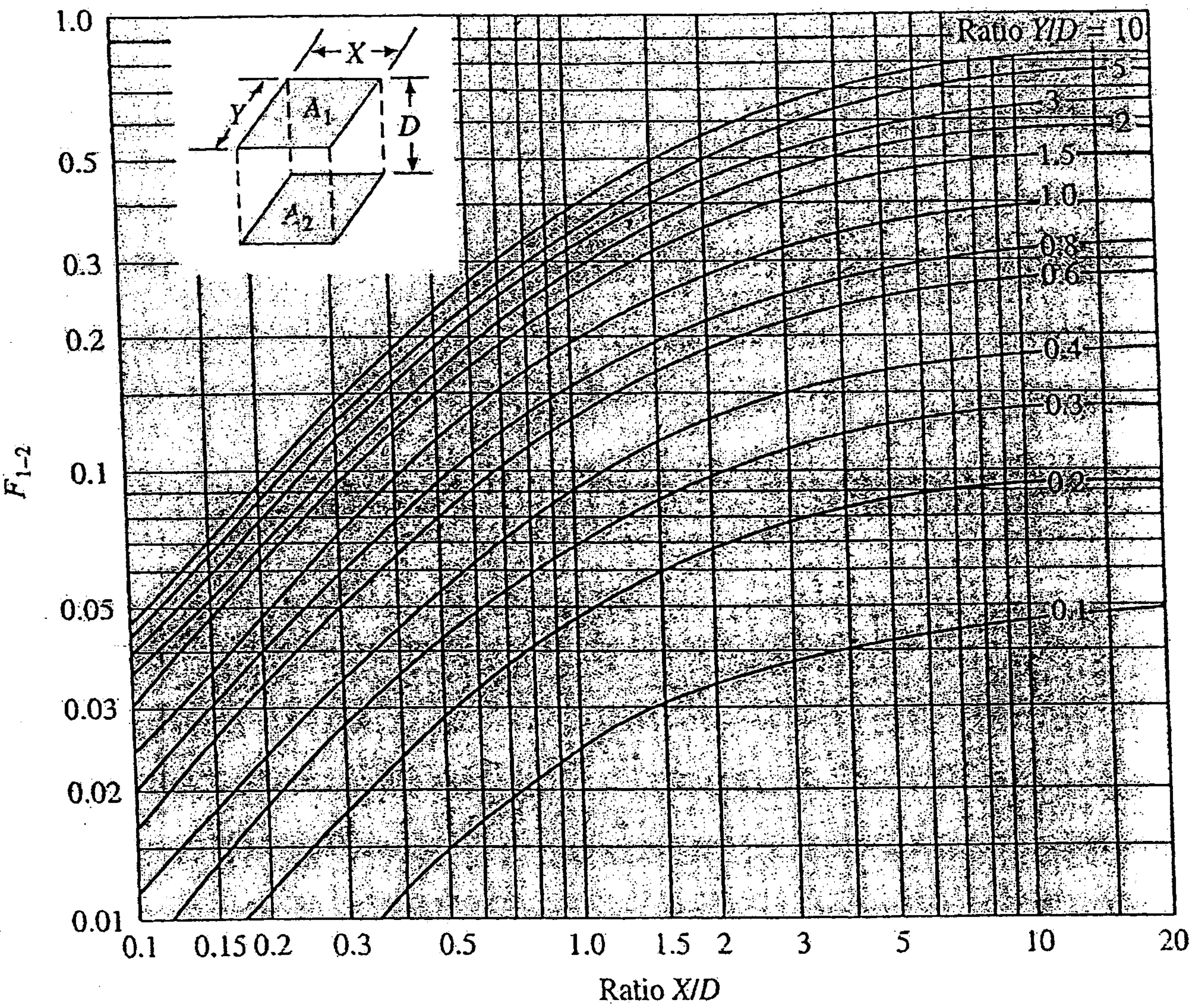


Figure 4.5 Radiation shape factor for radiation between parallel rectangles.

Table Q. 4 – 6 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

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 Q. 5 [a] 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 K	ρ, kg/m³	μ, kg/m s	k, W/m K	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$, 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	3.05	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			

Equations	$E_{b_{0-\infty}} = \sigma T^4$ $E_{b\lambda} = \dfrac{C_1\lambda^{-5}}{e^{C_2/\lambda T} - 1}$ $\lambda_{max} T = C_3$ $\mathrm{Re} = \dfrac{4m}{\mu_l b}$
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 $(\mathrm{Re} \ge 1800)$	$\dfrac{\bar{h}(v^2/g)^{1/3}}{k_l} = \dfrac{\mathrm{Re}}{8750 + 58\,\mathrm{Pr}^{-0.5}(\mathrm{Re}^{0.75} - 253)}$

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) $C_1 = 3.743\times10^8$ $W\mu/m^2$ $C_2 = 1.4387\times10^8$ μmK $C_3 = 2897.6$ μmK

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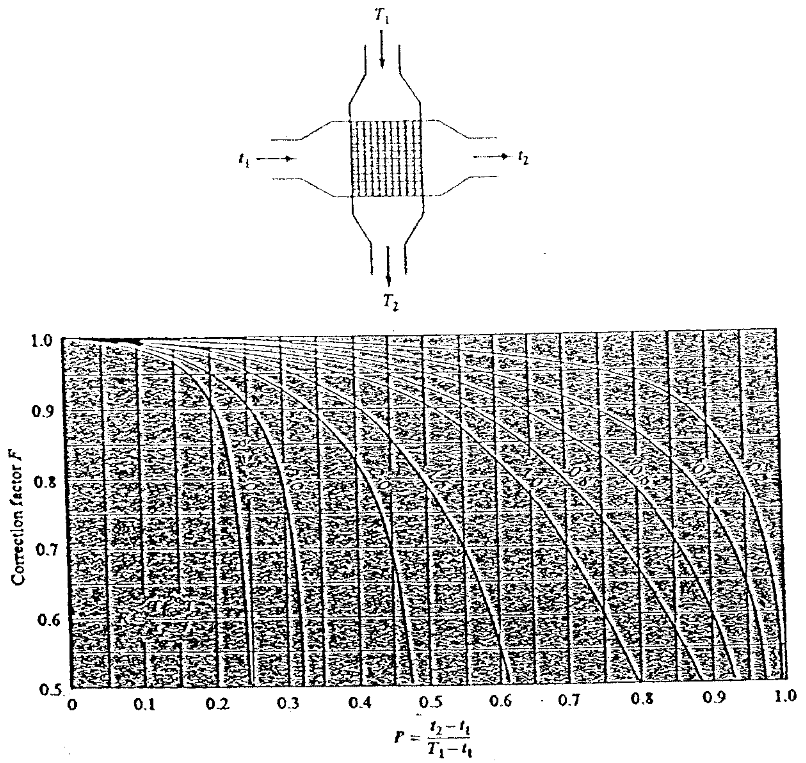
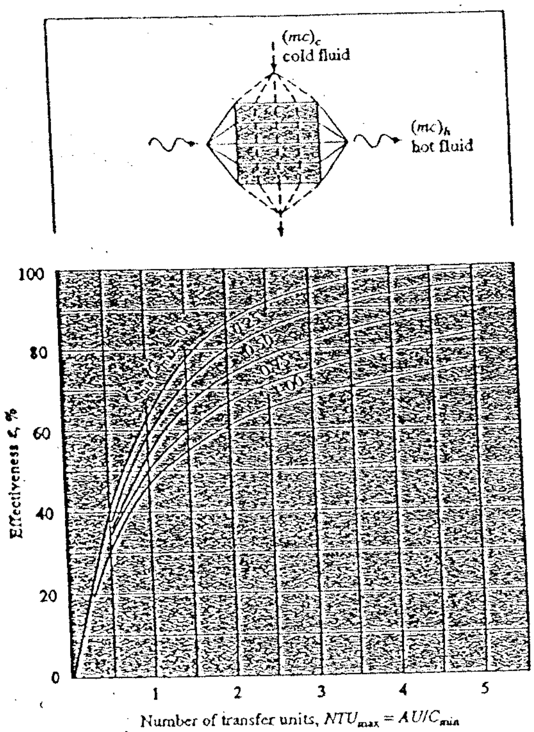


Correction-factor plot for single-pass cross-flow exchanger, both fluids unmixed.



Effectiveness for cross-flow exchanger with fluids unmixed.

Figure Q.6.1