UNIVERSITY OF JOHANNESBURG

PROGRAM	:	B ENG TECH *PHYSICAL 7 EXTRACTION METALLURGY*
SUBJECT	:	**HEAT & MASS TRANSFER II**
CODE	:	**HMTMTA2**
DATE	:	EXAMINATION 01 June 2019
DURATION	:	08:30 - 11:30
WEIGHT	:	40 : 60
TOTAL MARKS	:	100

EXAMINER	:	MR GA COMBRINK	Sanso Number
MODERATOR	:	MR J Prozzi	File Number 5113
NUMBER OF PAGES	:	9 PAGES	

INSTRUCTIONS	:	ALL THE ANSWERS MUST BE COMPLETED IN THE EXAM SCRIPS AND HANDED IN QUESTION PAPERS MUST BE HANDED IN.
REQUIREMENTS	:	1 POCKET CALCULATOR NO CORRECTION FLUID SHALL BE USED ALL WORK SHALL BE HANDED IN.

INSTRUCTIONS TO CANDIDATES:

PLEASE ANSWER ALL THE QUESTIONS.

REFER TO APPENDICES FOR FURTHER INFORMATION AND EQUATIONS THAT MAY BE REQUIRED IN ANSWERING THE QUESTION IN EACH CASE.

QUESTION 1 **Heat Removal from Semi-Infinite Solid**

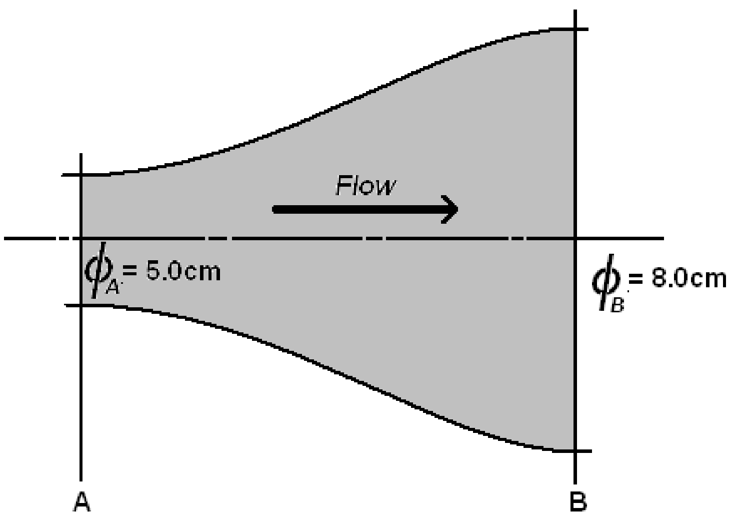
1. A 20metre long section of a 3metre wide steel plate that is 30mm thick is at 300ºC. Its surface is suddenly cooled to 100°C. How long for the temperature at a depth 5 mm has dropped to 150ºC?
2. If the material had been aluminium instead, under the same conditions how heat is removed in the time that it would take for the temperature at a depth 5mm below the surface to reach 150ºC
3. Which material (aluminium or steel) would have the most heat loss in the same period. (do the calculation needed to prove it.)

Assume α=8.4x10^{-5} m^2/s k_{steel} =50.2W/m°C , $k_{aluminium}$ = 205.0W/m°C

(See Appendix B Sheet for equations, and further data. Also refer to attached TableA-1 at Appendix A for relevant erf function values) **[12]**

QUESTION 2 Water Flow in a Diffuser

Water at 40ºC flows at 10kg/second through the diffuser arrangement shown below. Disregarding the effect of friction, determine the change in static pressure between section A and section B. (Diameters as indicated on drawing) [See Formulation sheet for equations.] Density of water at the flow temperature is 1000kg/m^3 g_c = 9.806kg_m m/kg_f s_2 =1 kg.m/Ns_2



[6]

QUESTION 3 Reynolds Number

What is the flow regime for oil of density 0.953kg/litre and that has a kinematic viscosity at 40ºC of 46cSt if it flows at 8kg per second in a tube with a circular profile of diameter 80mm. 1cSt $=10^{-6}$ m^2/s

[8]

QUESTION 4

4. A stainless-steel ball (18% Cr, 8% Ni) 150 mm in diameter is initially at a uniform temperature of 18ºC and is suddenly immersed in an oil liquid at 220°C with h= 136 $W/m^{2o}C$. Using the lumped-capacity method of analysis, calculate the time necessary for the ball temperature to reach 200ºC

[13]

QUESTION 5 IGNORE THE EFFECTS OF RADIATION IN THIS EXERCISE!

5 On one side of a concrete wall a heat flux of 1430W/m^2 is transferred into the wall (i.e. that is what enters the wall). The wall is 20 cm thick and has an average value of thermal conductivity of 0.75W/m°C.

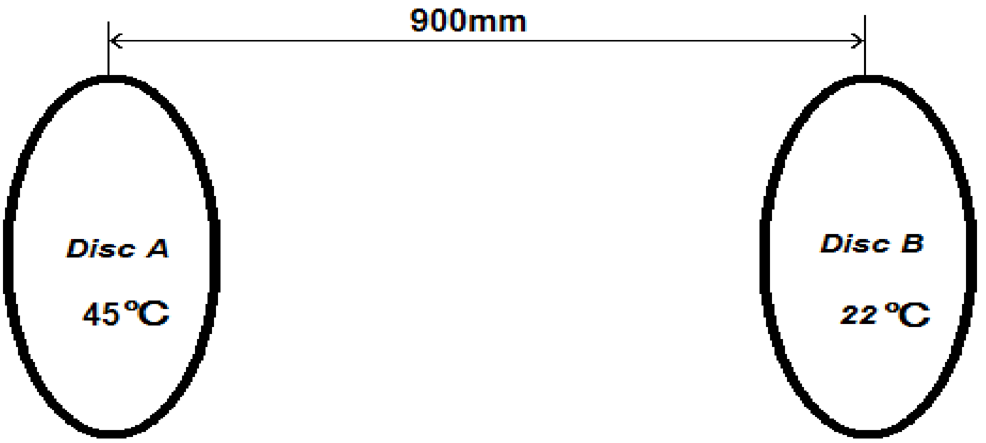
5.1 What will be the change in temperature over the wall (i.e. the temperature gradient) under steady state conditions (ΔT). *(7marks)*

5.2 Now determine the walls surface temperatures when the opposite side of the wall is exposed to air at 47°C. (take h = 63W/m^2°C). *(8marks)*

[15]

QUESTION 6

Two similar sized (20 cm diameter) tin discs that are parallel to each other are buried in crushed iron ore, (see sketch below). They are 900 mm apart and Disc A is kept at 45℃ whereas disc B is at 22℃. Using shape factors calculate what is the heat transfer between the two discs in the sketch? Use data in the appendices and the thermal conductivity provided in question 5 below.



[16]

QUESTION 7

A large steel plate of 100 mm thick and initially at 200ºC is suddenly exposed to moving air at a temperature of 60ºC. h = 528W/(m^2.ºC).
k_{steel} =50.2W/m ºC. α =8.4 x 10^{-5} m^2/s density steel = 7800kg/m^3 $C_{p\ steel}$ = 0.420kJ/kgºC
Using Heisler charts (see Appendix B) to find the solutions to the questions below using θ_o/θ_i.

7.1 Calculate the temperature at a depth of 15mm from the steel plate surface 1minute after the plate has been exposed to the 60ºC environment. *(10marks)*
7.2 Calculate the amount of energy that is lost from the steel plate in 3 minutes. *(5marks)*

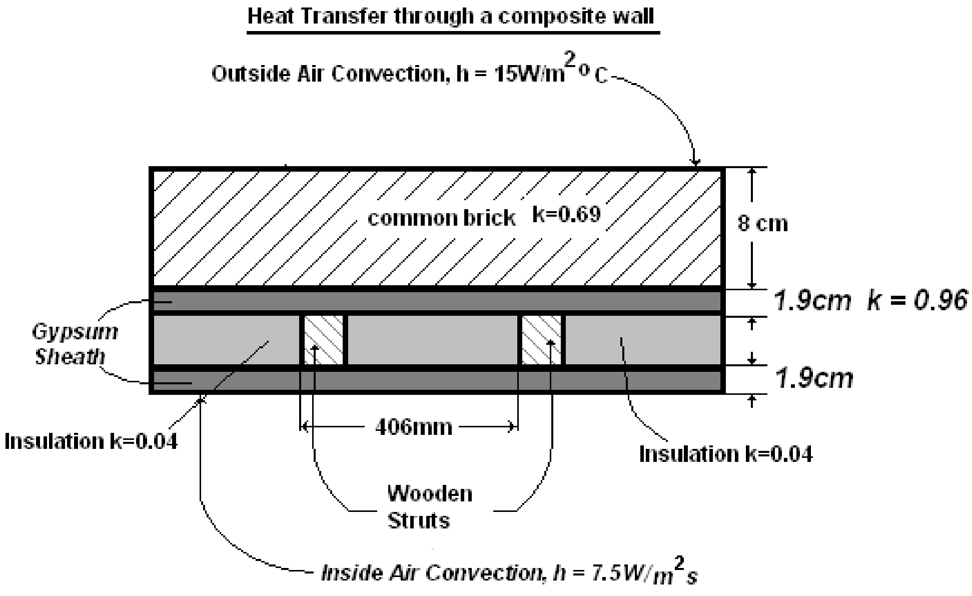
[15]

QUESTION 8

The sketch below represents a cross sectional view of a typical wall as seen from above.
8.1 Draw the equivalent thermal resistance circuit for the wall that is represented in the sketch and, *(5marks)*
8.2 Calculate equivalent overall thermal resistance in the system. *(10marks)*

Notes:

- The wooden Struts are 56mm wide (therefore the width of the insulation between two slats is (406 - 56) mm = 350mm wide).
- The thickness of the wooden struts is also 56mm.
- The units of the k values set out on the sketch is [W/(m.ºC)] and k_{wood} is 2W/(m.ºC)
- The two layers of Gypsum are identical in every way i.e. they have the same k values.



[15]

Total Marks **[100]**

Appendix A "erf" Function values

Table The error function.

$\frac{x}{2\sqrt{\alpha\tau}}$	$\text{erf}\,\frac{x}{2\sqrt{\alpha\tau}}$	$\frac{x}{2\sqrt{\alpha\tau}}$	$\text{erf}\,\frac{x}{2\sqrt{\alpha\tau}}$	$\frac{x}{2\sqrt{\alpha\tau}}$	$\text{erf}\,\frac{x}{2\sqrt{\alpha\tau}}$
0.00	0.00000	0.76	0.71754	1.52	0.96841
0.02	0.02256	0.78	0.73001	1.54	0.97059
0.04	0.04511	0.80	0.74210	1.56	0.97263
0.06	0.06762	0.82	0.75381	1.58	0.97455
0.08	0.09008	0.84	0.76514	1.60	0.97636
0.10	0.11246	0.86	0.77610	1.62	0.97804
0.12	0.13476	0.88	0.78669	1.64	0.97962
0.14	0.15695	0.90	0.79691	1.66	0.98110
0.16	0.17901	0.92	0.80677	1.68	0.98249
0.18	0.20094	0.94	0.81627	1.70	0.98379
0.20	0.22270	0.96	0.82542	1.72	0.98500
0.22	0.24430	0.98	0.83423	1.74	0.98613
0.24	0.26570	1.00	0.84270	1.76	0.98719
0.26	0.28690	1.02	0.85084	1.78	0.98817
0.28	0.30788	1.04	0.85865	1.80	0.98909
0.30	0.32863	1.06	0.86614	1.82	0.98994
0.32	0.34913	1.08	0.87333	1.84	0.99074
0.34	0.36936	1.10	0.88020	1.86	0.99147
0.36	0.38933	1.12	0.88079	1.88	0.99216
0.38	0.40901	1.14	0.89308	1.90	0.99279
0.40	0.42839	1.16	0.89910	1.92	0.99338
0.42	0.44749	1.18	0.90484	1.94	0.99392
0.44	0.46622	1.20	0.91031	1.96	0.99443
0.46	0.48466	1.22	0.91553	1.98	0.99489
0.48	0.50275	1.24	0.92050	2.00	0.995322
0.50	0.52050	1.26	0.92524	2.10	0.997020
0.52	0.53790	1.28	0.92973	2.20	0.998137
0.54	0.55494	1.30	0.93401	2.30	0.998857
0.56	0.57162	1.32	0.93806	2.40	0.999311
0.58	0.58792	1.34	0.94191	2.50	0.999593
0.60	0.60386	1.36	0.94556	2.60	0.999764
0.62	0.61941	1.38	0.94902	2.70	0.999866
0.64	0.63459	1.40	0.95228	2.80	0.999925
0.66	0.64938	1.42	0.95538	2.90	0.999959
0.68	0.66278	1.44	0.95830	3.00	0.999978
0.70	0.67780	1.46	0.96105	3.20	0.999994
0.72	0.69143	1.48	0.96365	3.40	0.999998
0.74	0.70468	1.50	0.96610	3.60	1.000000

APPENDIX B
Equation and Data Sheet

$$\frac{T_{(x,\tau)} - T_o}{T_i - T_o} = \text{erf} \frac{X}{2\sqrt{\alpha\tau}} \quad \text{And} \quad \frac{Q_o}{A} = 2k(T_o - T_i)\sqrt{\frac{\tau}{\pi\alpha}}$$

"erf" function values at Appendix A

$U = \dot{m}/(\boldsymbol{\rho}A)$ $\qquad \frac{\Delta P}{\rho} = \frac{1}{2}\frac{\Delta V^2}{g_c} = constant$

Reynolds numbers

The units for static or dynamic viscosity is Poise(P) often quoted in [cP] = [kg/m^{2}s]
That for kinematic is Stokes (st). For kinematic viscosity ***1cSt =1m^2/s***

Reynolds number in a tube: $\boldsymbol{Re_d = U_m d/v}$

$\boldsymbol{Re_x = U_\infty x/v}$

$Nu_x = h_x.x/k = 0.332 Re_x^{1/2} Pr^{1/3}$

$\boldsymbol{C_p = 1.006\ kJ/kg^oC}$

$$q = \bar{h}A(T_w - T_\infty)$$

$$\frac{\delta}{x} = \frac{5.0}{Re_x^{0.5}}$$

θ_o/θ_i. Where $\theta_o = T_o - T_\infty$ *and* $\theta_i = T_i - T_\infty$ *etc.*

$$\frac{Q_o}{A} = \frac{\rho c V \theta_i}{A}$$

$$\rho = \frac{P}{RT} \quad Assume\ R = 287 J/kgK$$

Heislar and other charts

Figure 4-10 | Temperature as a function of center temperature in an infinite plate of thickness 2*L*, from Reference 2.

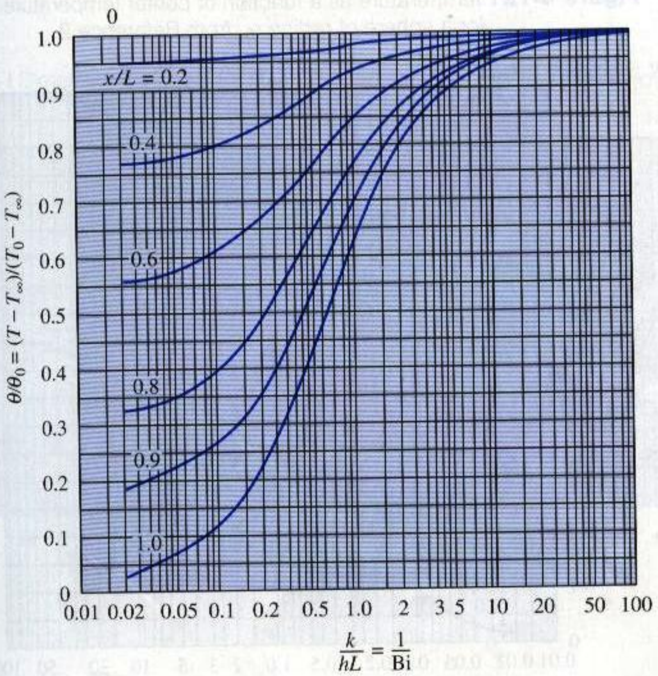
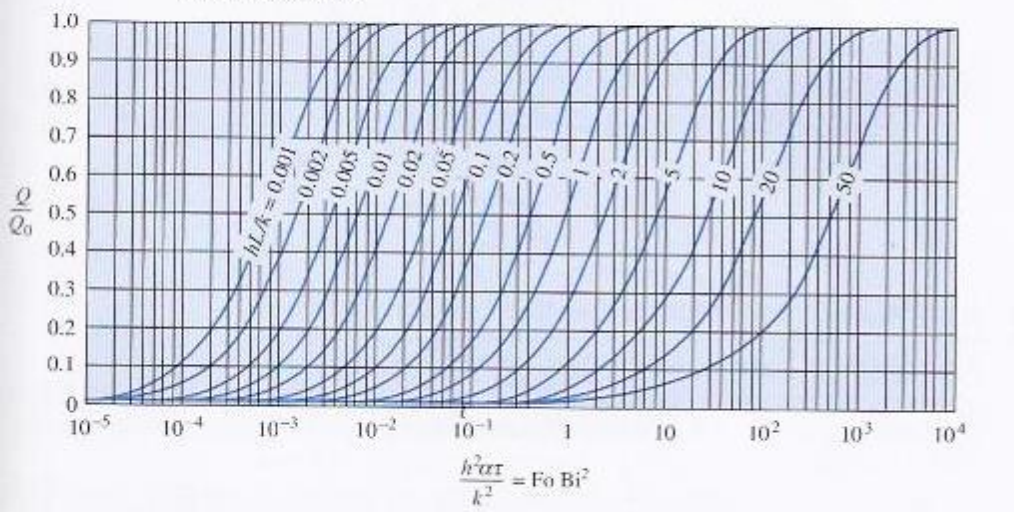


Figure 4-14 | Dimensionless heat loss Q/Q_0 of an infinite plane of thickness 2*L* with time, from Reference 6.



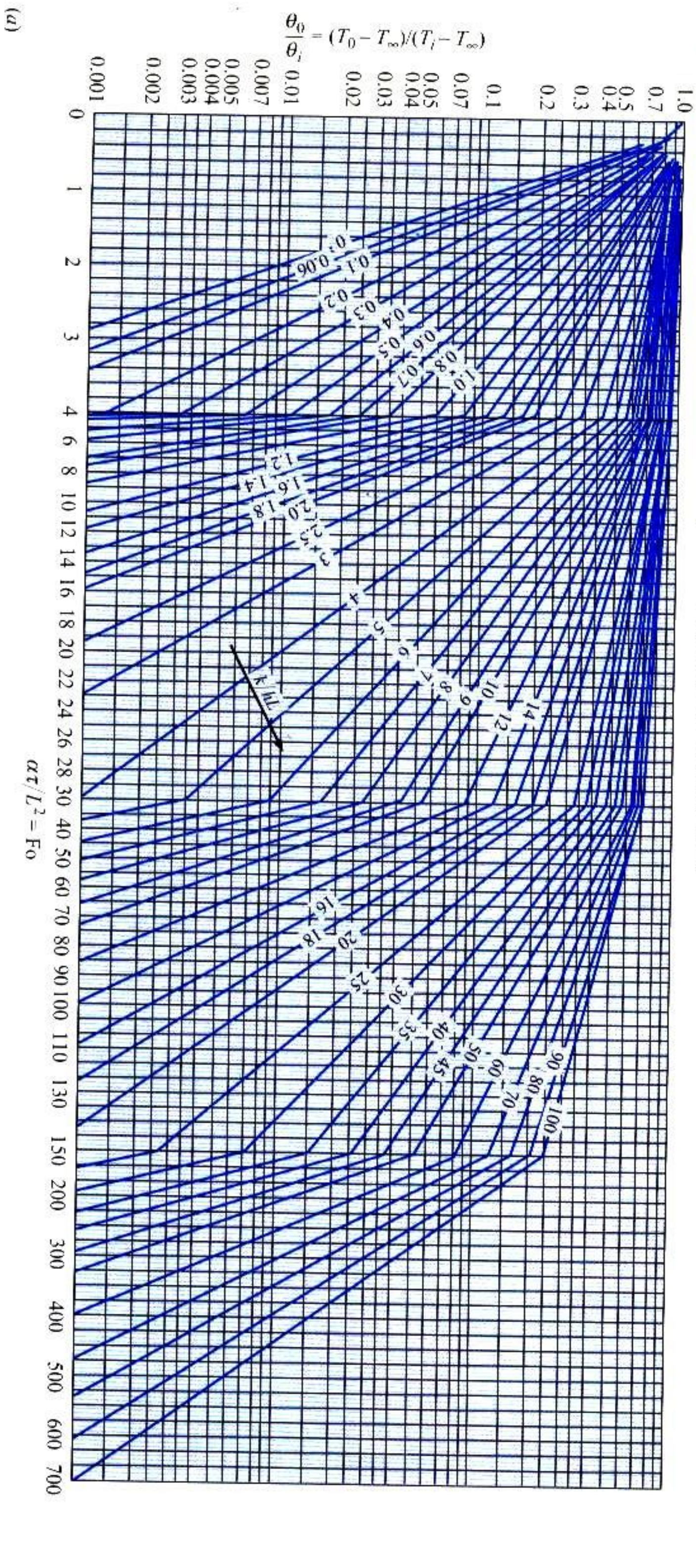
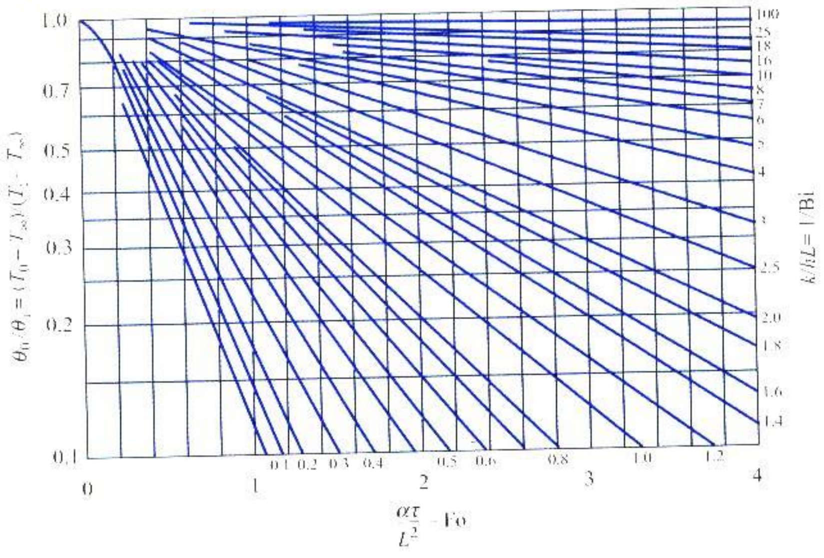


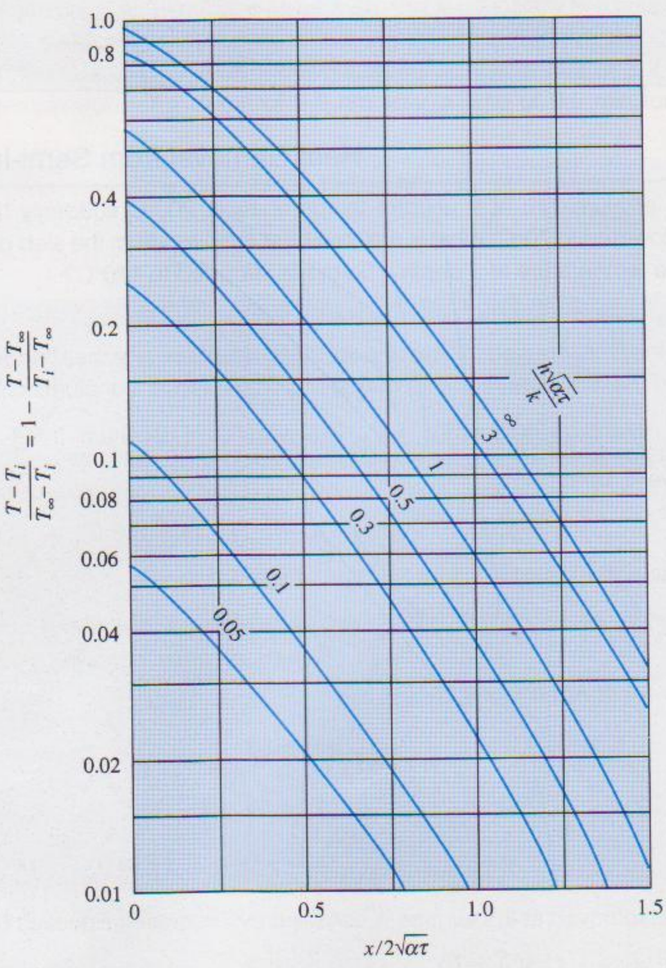
Figure 4-7 | Midplane temperature for an infinite plate of thickness $2L$: (a) full scale.

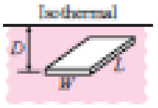
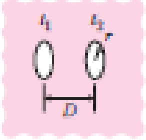
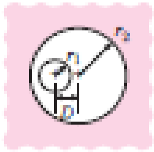
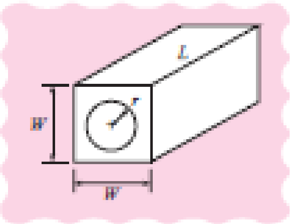
Figure 4-7 | (*Continued*). (*b*) expanded scale for 0 < Fo < 4, from Reference 2.



(*b*)

Figure 4-5 | Temperature distribution in the semi-infinite solid with convection boundary condition.



Physical system	Schematic	Shape factor	Restrictions
Thin rectangular plate of length L, buried in semi-infinite medium having isothermal surface		$\frac{\pi W}{\ln(4W/L)}$ $\frac{2\pi W}{\ln(4W/L)}$ $\frac{2\pi W}{\ln(2\pi D/L)}$	$D = 0$, $W > L$ $D \gg W$, $W > L$ $W \gg L$, $D > 2W$
Parallel disks buried in infinite medium		$\frac{4\pi r}{\left[\frac{\pi}{2} - \tan^{-1}(r/D)\right]}$	$D > 5r$ $\tan^{-1}(r/D)$ in radians
Eccentric cylinders of length L		$\frac{2\pi L}{\cosh^{-1}\left(\frac{r_1^2 + r_2^2 - D^2}{2r_1 r_2}\right)}$	$L \gg r_2$
Cylinder centered in a square of length L		$\frac{2\pi L}{\ln(0.54\,W/r)}$	$L \gg W$