UNIVERSITY OF JOHANNESBURG

PROGRAM	:	NATIONAL DIPLOMA *ENGINEERING METALLURGY*
SUBJECT	:	**HEAT & MASS TRANSFER II**
CODE	:	**HMR21-1**
DATE	:	SUMMER EXAMINATION 2014 5 NOVEMBER 2014
DURATION	:	(SESSION 2) 12:30 - 15:30
WEIGHT	:	40 : 60
TOTAL MARKS	:	100

EXAMINER	:	MR GA COMBRINK	Sanso Number
MODERATOR	:	MR M KALEMBA	File Number 5113
NUMBER OF PAGES	:	12 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 20 metre long section of a 3metre wide steel plate that is 30mm thick is at 200°C. Its surface is suddenly cooled to 100°C. How long for the temperature at a depth 5 mm has dropped to 150°C?
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 150°C

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)

[10]

QUESTION 2

Two infinite black plates at 500°C and 100°C exchange heat by radiation. Calculate the heat-transfer rate per unit area. If another perfectly black plate is placed between the 500°C and 100°C plates, by how much is the heat transfer reduced? What is the temperature of the center plate?

[5]

QUESTION 3

Calculate the radiation heat exchange in 1 day between two perfectly black flat planes that are separated from each other by a constant 100cm by a vacuum having the area of the surface of a 0.7-m-diameter sphere when the planes are maintained at 70 K and 300 K.

[5]

QUESTION 4 *Design (ECSA ELO)*

A woman informs an engineer that she frequently feels cooler in the summer when standing in front of an open refrigerator. The engineer tells her that she is only "imagining things" because there is no fan in the refrigerator to blow the cool air over her. A lively argument ensues. Whose side of the argument do you take? Why?

[5]

QUESTION 5 *Design (ECSA ELO)*

A vertical cylinder 1,8m tall and 300mm in diameter might be used to approximate a man for heat-transfer purposes. Suppose the surface temperature of the cylinder is 78˚F, h=2 Btu/h ft^2˚F, the surface emissivity is 0.9, and the cylinder is placed in a large room where the air temperature is 68˚F and the wall temperature is 45˚F. Calculate the heat lost from the cylinder. Repeat for a wall temperature of 80˚F. What do you conclude from these calculations?

General formula temperature conversion from x˚F to ˚C is as follows: - x˚F =[(x-32)/1.8]°C

[10]

QUESTION 6

Suppose a 75 mm schedule 80 pipe that has a wall thickness of 5mm is covered with 25 mm of an insulation having k =60 milliW/m˚C and the outside of the insulation is exposed to an environment having h=10W/m^2˚C and T_∞ = 20˚C. The temperature of the inside of the pipe is 250˚C. For unit length of the pipe calculate (a) overall thermal resistance and (b) heat loss.

[10]

QUESTION 7

7. Calculate the R value for the following insulations: -
   - 7.1. Urethane foam at 200K
   - 7.2. Fiberglass mats at 350°C
   - 7.3. Mineral wool blocks at 773K
   - 7.4. Calcium silicate blocks at 1000°C
   - 7.5. Cellular glass blocks and boards at 400°C

Use information provided in datasheet.

[10]

QUESTION 8

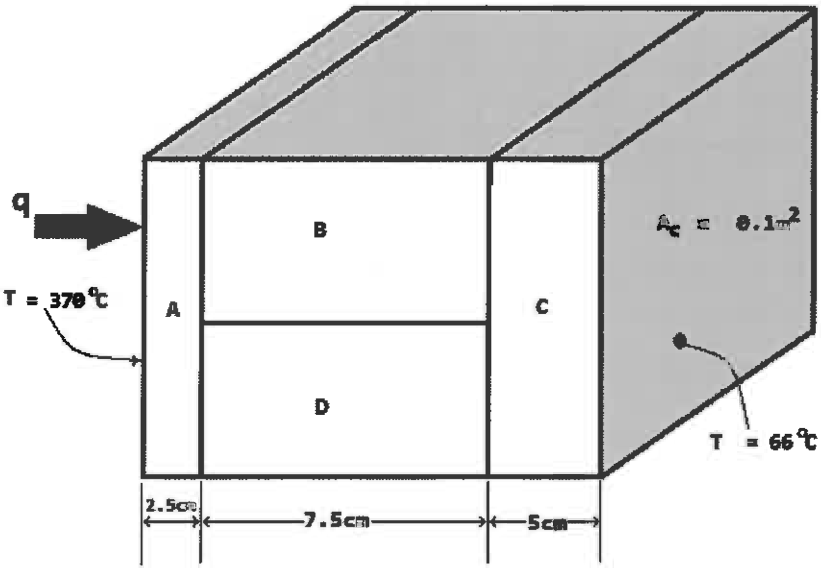
A steel pipe with 5-cm OD is covered with a 6.4-mm asbestos insulation **[k =0.096 Btu/h ft** ˚F] followed by a 2.5-cm layer of fiberglass insulation **[k =0.028 Btu/h ft** ˚F]. The pipe-wall temperature is 315˚C, and the outside insulation temperature is 38˚C. Calculate the interface temperature between the asbestos and fiberglass.

Useful information: 1 W/m·˚C=0.5778 Btu/h.ft.˚F and conversely 1 Btu/h.ft.˚F = 1.7307 W/m·˚C

[10]

QUESTION 9

Find the heat transfer per unit area through the composite wall in the figure below.
Assume one-dimensional heat flow.



k_A = 150 W/m°C
k_B = 30 W/m°C
k_C = 50 W/m°C
k_D = 70 W/m°C

$Area_B = Area_D$

[10]

QUESTION 10

A horizontal pipe having a surface temperature of 67°C and diameter of 25 cm is buried at a depth of 1.2 m in the earth at a location where k =1. 8W/m°C. The earth surface temperature is 15°C. Calculate the heat lost by the pipe per unit length. See Attached datasheet at Appendix A for useful information.

[15]

QUESTION 11 Unsteady State Conduction

An infinite plate having a thickness of 2.5 cm is initially at a temperature of 150°C, and the surface temperature is suddenly lowered to 30°C. The thermal diffusivity of the material is 1.8×10^{-6} m²/s. Calculate the center-plate temperature after 1 min by summing the first four non-zero terms of the equation provided below. Check the answer using the Heisler charts.

$$\frac{\theta}{\theta_i} = \frac{T-T_1}{T_i-T_1} = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}e^{-[n\pi/2L]^2\alpha\tau}.\ \sin\frac{n\pi x}{2L} \qquad \text{where } n = 1, 3, 5 \ldots$$

[15]

QUESTION 12

Oxygen at a pressure of 2 atm and 27°C blows across a 50-cm^2 plate at a velocity of 30 m/s. The plate temperature is maintained constant at 127°C. Calculate the Reynolds number as well as the total heat lost by the plate. (Take the viscosity of air at 2 atm to be 10.4 x 10^{-6} mm^2/s and $h =$ 123W/m^2.°C)

[8]

Total Marks **[100]**

Appendix A "erf" Function values

Table The error function

$\frac{x}{2\sqrt{\alpha t}}$	$\mathrm{erf}\,\frac{x}{2\sqrt{\alpha t}}$	$\frac{x}{2\sqrt{\alpha t}}$	$\mathrm{erf}\,\frac{x}{2\sqrt{\alpha t}}$	$\frac{x}{2\sqrt{\alpha t}}$	$\mathrm{erf}\,\frac{x}{2\sqrt{\alpha t}}$
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	0.88679	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

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

Reynolds numbers

The units for static or dynamic viscosity is Poise(P) often quoted in [cP] = [kg/m²s]
That for kinematic is Stokes (st). For kinematic viscosity ***1cSt =1m²/s***

Reynolds number in a tube: $\qquad$ $Re_d = U_m d/v$

$Re_x = U_\infty x/v$

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

$C_p = 1.006\ kJ/kg°C$

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

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

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

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

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

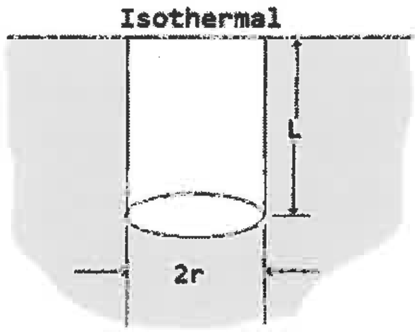
Table for use with Question 7

Insulation Types and applications

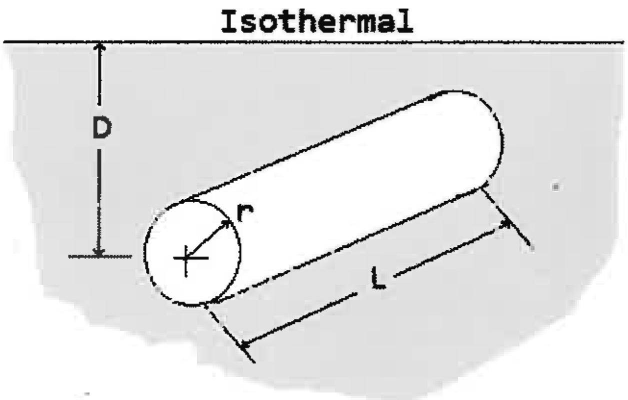
	Type	*Temperature range °C*	*Thermal Conductivity milliW/m °C**	*Density Kg/m³*	*Application*
1	Linde evacuated superinsulation	−240–1100	0.0015–0.72	Variable	Many
2	Urethane foam	−180–150	16–20	25–48	Hot and cold pipes
3	Urethane foam	−170–110	−16–20	32	Tanks
4	Cellular glass blocks	−200–200	29–108	110–150	Tanks and pipes
5	Fiberglass blanket for wrapping	−80–290	22–78	10–50	Pipe and pipe fittings
6	Fiberglass blankets	−170–230	25–86	10–50	Tanks and equipment
7	Fiberglass preformed shapes	−50–230	32–55	10–50	Piping
8	Elastomeric sheets	−40–100	36–39	70–100	Tanks
9	Fiberglass mats	60–370	30–55	10–50	Pipe and pipe fittings
10	Elastomeric preformed shapes	−40–100	36–39	70–100	Pipe and fittings
11	Fiberglass with vapour barrier blanket	−5–70	29–45	10–32	Refrigeration lines
12	Fiberglass without vapour barrier jacket	to 250	29–45	24–48	Hot piping
13	Fiberglass boards	20–450	33–52	25–100	Boilers, tanks, heat exchangers
14	Cellular glass blocks and boards	20–500	29–108	110–150	Hot piping
15	Urethane foam blocks and boards	100–150	16–20	25–65	Piping
16	Mineral fibre preformed shapes	to 650	35–91	125–160	Hot piping
17	Mineral fibre blankets	to 750	37–81	125	Hot piping
18	Mineral wool blocks	450–1000	52–130	175–290	Hot piping
19	Calcium silicate blocks, boards	230–1000	32–85	100–160	Hot piping, boilers chimney linings
20	Mineral fibre blocks	to 1100	52–130	210	Boilers and tanks

*note that this value is provided in *milliWatts/m. °C* (and not in W/m°C).

Shape factors:

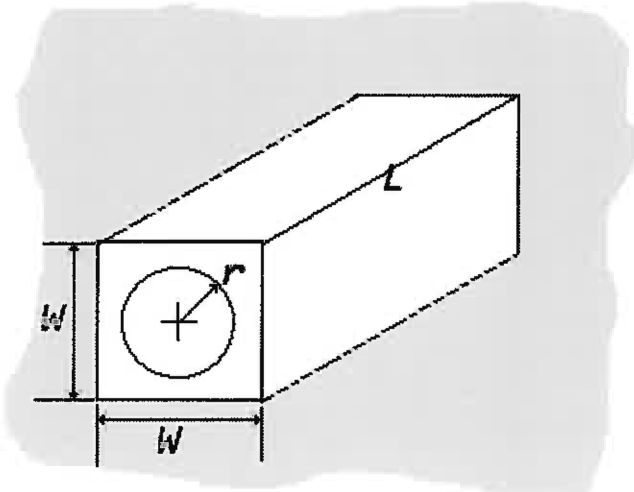


$$S = \frac{2\pi L}{\ln\left(\frac{2L}{r}\right)} \qquad L \gg 2r$$



$$S = \frac{2\pi L}{\cosh^{-1}\left(D/r\right)} \qquad L \gg r$$

$$S = \frac{2\pi L}{\ln\left(D/r\right)} \qquad L \gg r \ \& \ D > 3r$$



$$S = \frac{2\pi L}{\ln\left(0.54\, W/r\right)}$$

$L \gg W$

Heislar and other charts

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

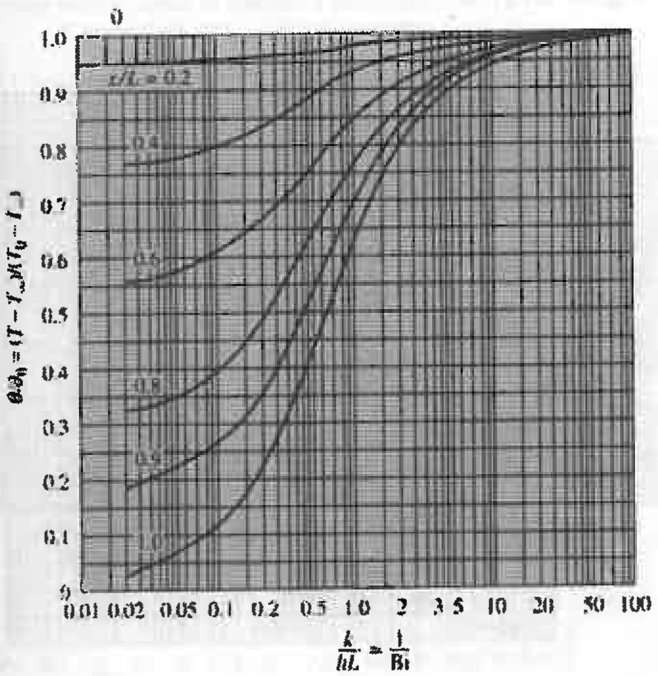


Figure 4-14 | Dimensionless heat loss Q/Q_0 of an infinite plane of thickness $2L$ with time, from Reference 6.

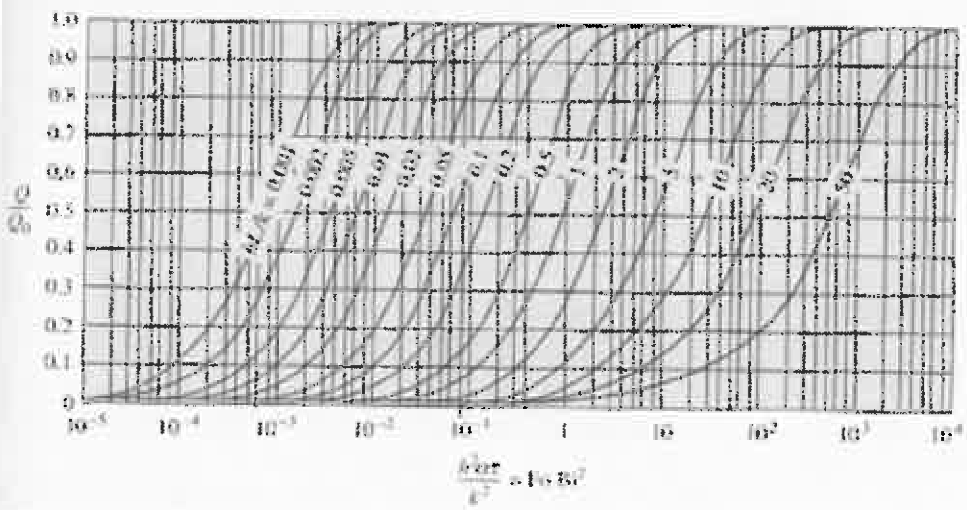


Figure 4-7 | Midplane temperature for an infinite plate of thickness 2L: (a) full scale

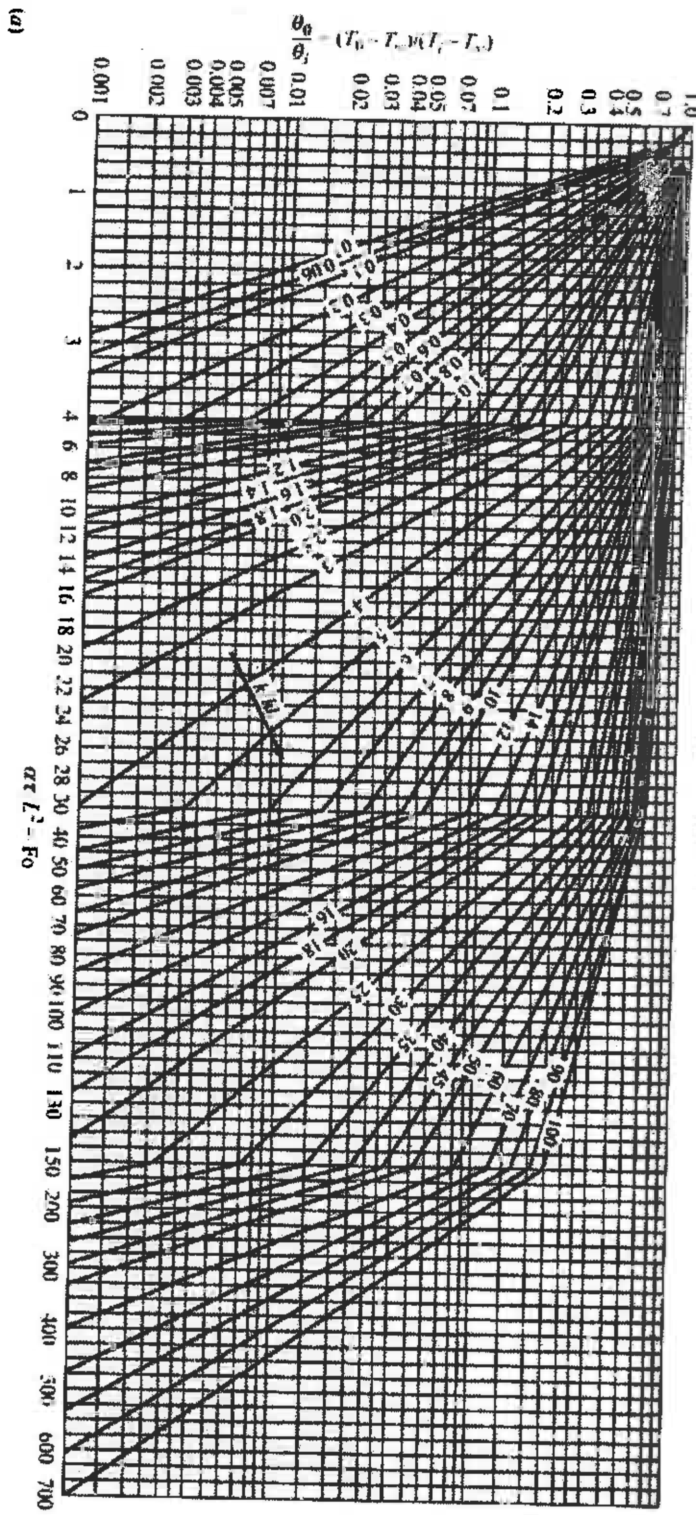
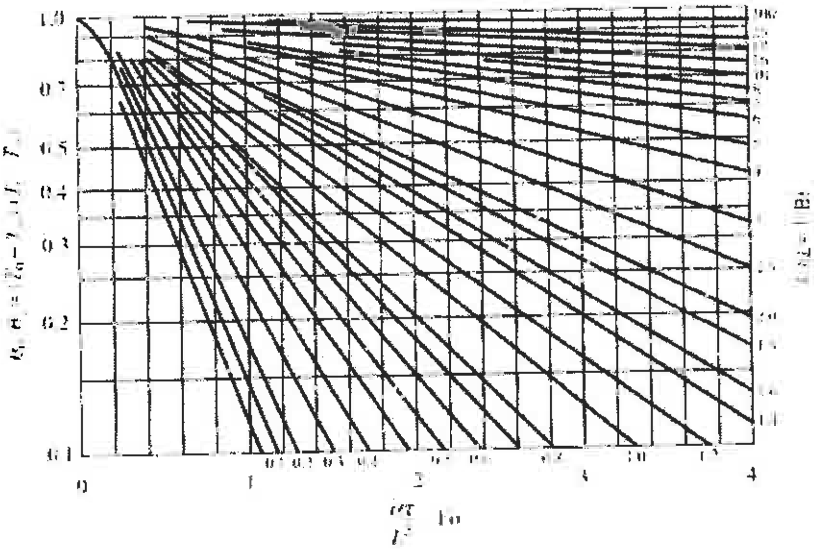


Figure 4-7 | (*Continued*) (*b*) expanded scale for 0 < Fo < 4, from Reference 2



(*b*)

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