UNIVERSITY OF JOHANNESBURG

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|---|---|---|
| **PROGRAM** | : NATIONAL DIPLOMA<br>*ENGINEERING METALLURGY* | |
| **SUBJECT** | : **HEAT & MASS TRANSFER II** | |
| **CODE** | : **HMR21-1** | |
| **DATE** | : SUMMER SSA EXAMINATION 2015<br>11 DECEMBER 2015 | |
| **DURATION** | : (SESSION 1) 08:00 - 11:00 | |
| **WEIGHT** | : 40: 60 | |
| **TOTAL MARKS** | : 80 | |

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|---|---|---|
| **EXAMINER** | : MR GA COMBRINK | Sanso Number |
| **MODERATOR** | : MR M KALEMBA | File Number 5113 |
| **NUMBER OF PAGES** | : 11 PAGES | |

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|---|---|
| **INSTRUCTIONS** | : ALL THE ANSWERS MUST BE COMPLETED IN THE EXAM SCRIPS AND HANDED IN<br>QUESTION PAPERS MUST BE HANDED IN. |
| **REQUIREMENTS** | : 1 POCKET CALCULATOR<br>NO CORRECTION FLUID SHALL BE USED<br>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.

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

1.1. A semi-infinitely large steel plate 40mm thick is at a constant temperature of 200°C. Suddenly its surface is cooled to 150°C. How long does it take for the temperature at a depth 12 mm from the plate surface to drop to 175°C?

1.2. A similar sized 40mm thick plate as described in question 1.1 above but now made out of an Aluminium alloy and also at a constant 200°C also now instantaneously has its surface cooled to 150°C. Calculate how long a point 12mm from the plate surface takes to reach a temperature of 175°C.

1.3. In 500 seconds calculate how much heat would have to be removed from the steel plate in question 1.1 to ensure that the temperature at a depth 3mm below the surface reaches 100°C if the surface temperature had initially (i.e. at time = 0 seconds) been suddenly cooled to 50°C.

1.4. Apart from saying that the two materials are different explain the reason for the difference between the two answers you got in questions 1.1 and 1.2 above.

Assume $\alpha_{Al} = \alpha_{Fe} = 8.4\text{x}10^{-5}$ m²/s $k_{steel}$ =50.0W/m.°C , $k_{Al}$ = 200.0W/m.°C

(See Appendix for possibly useful equations, further data and relevant erf function values)

[20]

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**QUESTION 2**

A rectangular column 2m high, 200mm wide by 200mm thick stands in the centre of a large room. Suppose the surface temperature of the column is 40°C, h=2 Btu/h ft$^{2}$°F, its surface emissivity is 0.9, and the room's air temperature is 70°F. In winter the room wall average temperature is12°C and in summer the same wall is at an average temperature of 85°F. Calculate the difference in heat lost from the column between what is lost in winter as opposed to what heat is lost from the column in summer. What do the results obtained tell you? What can be done in practice to improve the situation so that the heat loss will be similar in summer and in winter?

General formula temperature conversion from Fahrenheit to Centigrade is as follows: -
For "X""F =[("X°F"minus 32) all divided by 1.8] °C

[20]

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**QUESTION 3**

A 5cm diameter sphere is initially at a uniform temperature of 200°C when its surface is placed inside a chamber where the air temperature is at 20°C and thus situation has the effect that the sphere starts to cool down. If h =28W/m$^{2}$°C then using the lumped capacity method of analysis, calculate the time needed for the sphere temperature to reach 90°C.

[10]

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**QUESTION 4**

4. Calculate the R value for the following insulations: -
   4.1. Elastomeric sheets at 250K
   4.2. Fiberglass without vapour barrier jacket at 275°C
   4.3. Linder Superinsulation at 773K
   4.4. Copper sheets 1000°C
   4.5. Mineral fiber blanket at 400°C

Considering the five materials that you have calculated the R values for in the questions above, answer the following questions:-

4.6. Which of these materials would be your first choice for use as an insulator? Explain why?

4.7. Which of these materials would you use preferentially for heat transfer areas? Explain why?

[15]

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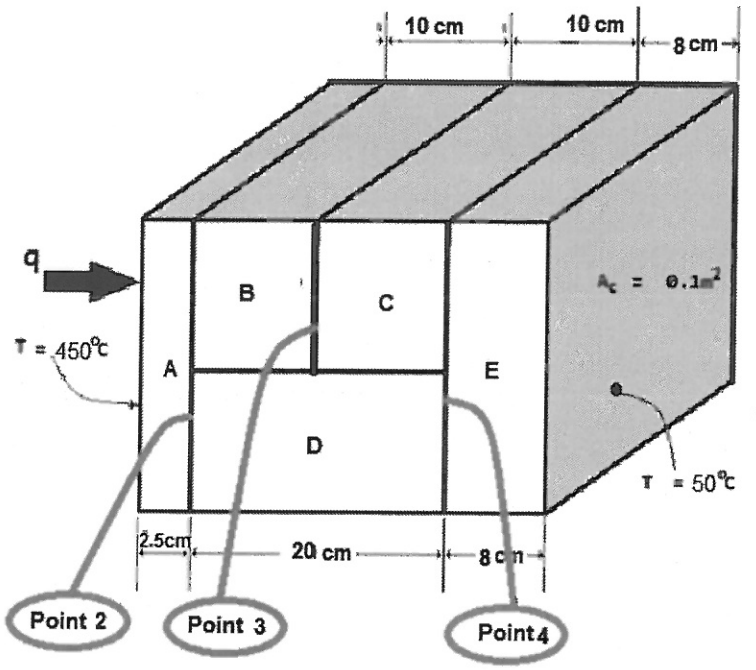
## Question 5

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
$k_E = 70$ W/m.°C

For the cross sectional areas B, C and D the following is valid; -
*Area B = Area C = Area D*
And, *The cross-sectional Area A = 2 times the size of cross sectional Area B*
Calculate what the temperature at point 2, point 3 and point 4 is under steady state conditions.

[25]

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Total Marks [90]

# Appendix A "erf" Function values

**Table** The error function.

| $\frac{x}{2\sqrt{\alpha\tau}}$ | erf $\frac{x}{2\sqrt{\alpha\tau}}$ | $\frac{x}{2\sqrt{\alpha\tau}}$ | erf $\frac{x}{2\sqrt{\alpha\tau}}$ | $\frac{x}{2\sqrt{\alpha\tau}}$ | 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 |

## Possibly useful equations and data

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

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

**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:*** $\qquad Re_d = U_m d/v$

$$Re_x = U_\infty x/v$$

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

$$C_p = 1.006\ kJ/kg^oC$$

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

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

Consider the ration $\theta_o/\theta_i$. 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 of relevant material data

| | Type | Temperature range °C | Thermal Conductivity (assume Linear function between limits) | Density Kg/m³ | Application |
|---|---|---|---|---|---|
| | *Insulation Types and applications* | | | | |
| 1 | Linde evacuated superinsulation | -240 to 1100 | 0.0015 to 0.72 *milliW/m °C** | Variable | Many |
| 2 | Urethane foam | -180 to 150 | 16 to 20 *milliW/m °C** | 25 to 48 | Hot and cold pipes |
| 3 | 1% Carbon Steel | 10 to 110 | 50.0 *W/m °C* | 7800 | various |
| 4 | Cellular glass blocks | -200 to 200 | 29 to 108 *milliW/m °C** | 110 to 150 | Tanks and pipes |
| 5 | Fiberglass blanket for wrapping | -80 to 290 | 22 to 78 *milliW/m °C** | 10 to 50 | Pipe and pipe fittings |
| 6 | Fiberglass blankets | -170 to 230 | 25 to 86 *milliW/m °C** | 10 to 50 | Tanks and equipment |
| 7 | Fiberglass preformed shapes | -50 to 230 | 32 to 55 *milliW/m °C** | 10 to 50 | Piping |
| 8 | Elastomeric sheets | -40 to 100 | 36 to 39 *milliW/m °C** | 70 to 100 | Tanks |
| 9 | Fiberglass mats | 60 to 370 | 30 to 55 *milliW/m °C** | 10 to 50 | Pipe and pipe fittings |
| 10 | Elastomeric preformed shapes | -40 to 100 | 36 to 39 *milliW/m °C** | 70 to 100 | Pipe and fittings |
| 11 | Fiberglass with vapour barrier blanket | -5 to 70 | 29 to 45 *milliW/m °C** | 10 to 32 | Refrigeration lines |
| 12 | Fiberglass without vapour barrier jacket | 0 to 250 | 29 to 45 *milliW/m °C** | 24 to 48 | Hot piping |
| 13 | Fiberglass boards | 20 to 450 | 33 to 52 *milliW/m °C** | 25 to 100 | Boilers, tanks, heat exchangers |
| 14 | Cellular glass blocks and boards | 20 to 500 | 29 to 108 *milliW/m °C** | 110 to 150 | Hot piping |
| 15 | Urethane foam blocks and boards | 100 to 150 | 16 to 20 *milliW/m °C** | 25 to 65 | Piping |
| 16 | Mineral fibre preformed shapes | 0 to 650 | 35 to 91 *milliW/m °C** | 125 to 160 | Hot piping |
| 17 | Mineral fibre blankets | 0 to 750 | 37 to 81 *milliW/m °C** | 125 | Hot piping |
| 18 | Mineral wool blocks | 450 to 1000 | 52 to 130 *milliW/m °C** | 175 to 290 | Hot piping |
| 19 | Calcium silicate blocks, boards | 230 to 1000 | 32 to 85 *milliW/m °C** | 100 to160 | Hot piping, boilers chimney linings |
| 20 | Mineral fibre blocks | 0 to 1100 | 52 to 130 *milliW/m °C** | 210 | Boilers and tanks |
| 21 | Copper | 0 to 100 | 400.0 *W/m °C** | 8900 | Various |
| 22 | Heat resistant Fibre Cement sheets | 0 to 200 | 360 *milliW/m °C** | 160 | Roof/wall sheets & cladding |
| 23 | Aluminium | 0 to 100 | 200W/m°C* | 2700 | Various |

*note that some of these values are provided in *milliWatts/m. °C* and others in W/m°C.



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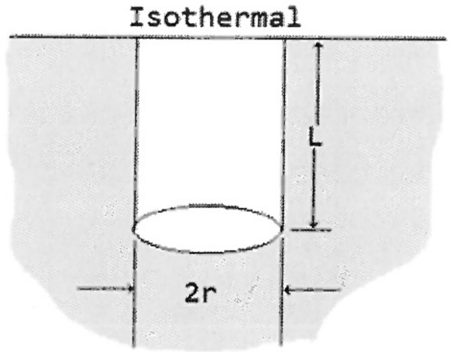
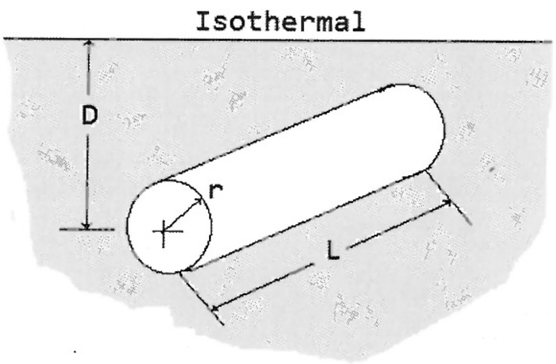
Shape factors:

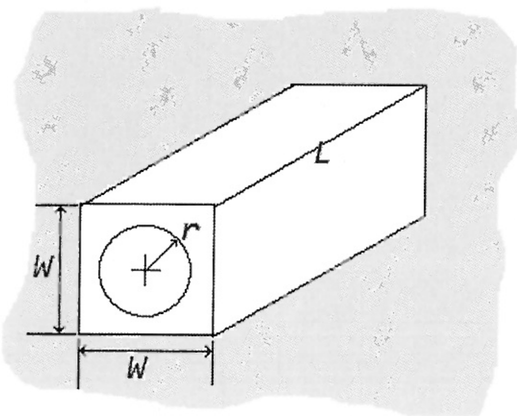



$$S = \frac{2\pi L}{\ln\left(2L/r\right)} \qquad L \gg 2r$$




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

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




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

$$L \gg W$$

## *Heislar and other charts*

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

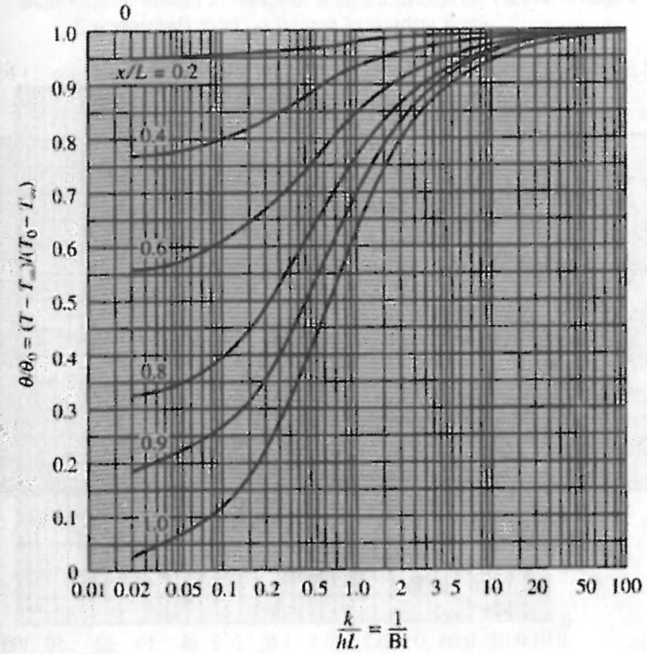



**Figure 4-14** | Dimensionless heat loss $Q/Q_0$ of an infinite plane of thickness $2L$ with time, from Reference 6.

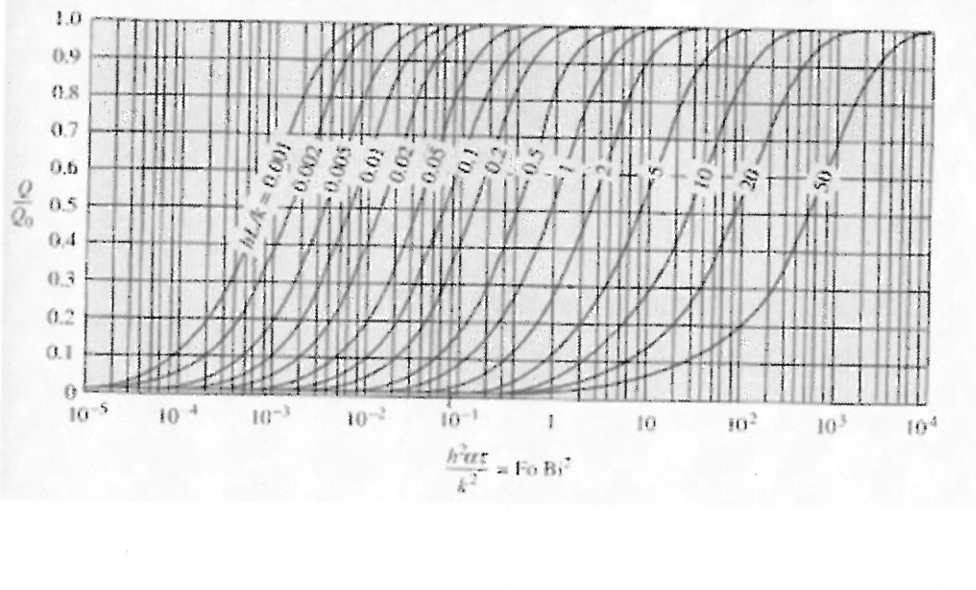
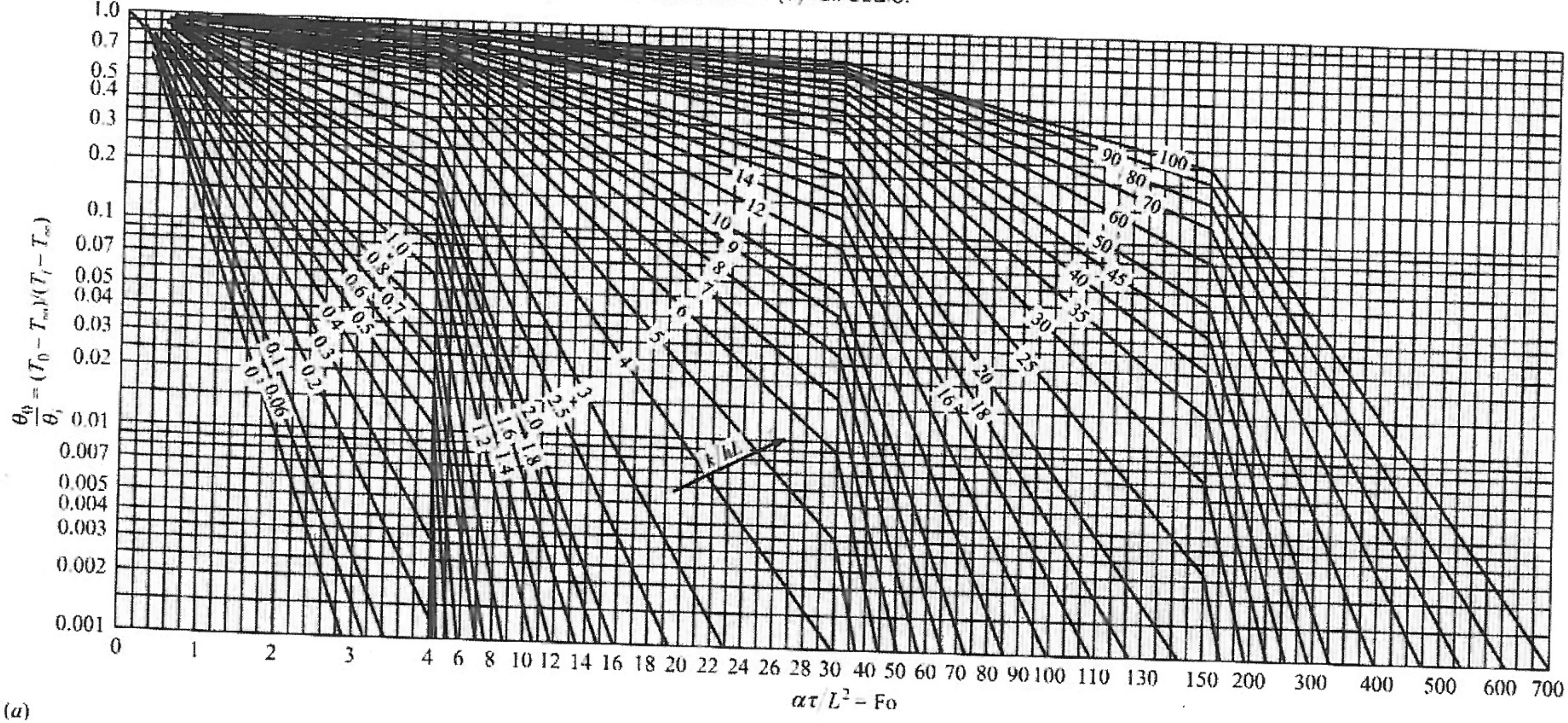
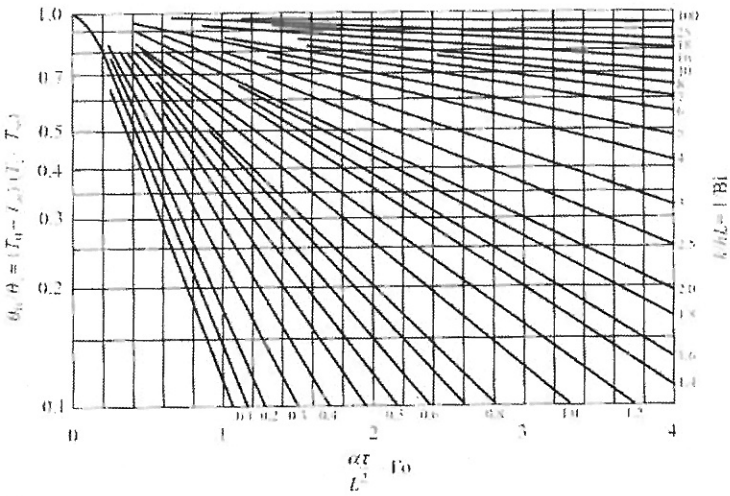


**Figure 4-7** | Midplane temperature for an infinite plate of thickness $2L$: ($a$) full scale.




($a$)

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.