UNIVERSITY OF JOHANNESBURG

PROGRAM	:	B ENG TECH *METALLURGY*	
SUBJECT	:	**HEAT & MASS TRANSFER II**	
CODE	:	**HMTMTA2**	
DATE	:	EXAMINATION 26 May 2018	
DURATION	:	3 Hours	
WEIGHT	:	40 : 60	
TOTAL MARKS	:	110	

EXAMINER	:	MR GA COMBRINK	Sanso Number
MODERATOR	:	MR J M PROZZI	File Number 5113
NUMBER OF PAGES	:	11 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. An infinitely long section of a 3metre wide steel plate that is 30mm thick is initially at 300°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
3. Which material (aluminium or steel) would have the most heat loss in the same period. (do the calculation needed to prove it.)

Assume $\alpha = 8.4 \times 10^{-5}$ m²/s $k_{steel} = 50.2$W/m°C , $k_{aluminium} = 205.0$W/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) **[20]**

QUESTION 2

A stainless-steel rod (18% Cr, 8% Ni) 6.4 mm in diameter is initially at a uniform temperature of 25°C and is suddenly immersed in a liquid at 150°C with h= 120 W/m²°C. Using the lumped-capacity method of analysis, calculate the time necessary for the rod temperature to reach 120°C

[10]

QUESTION 3

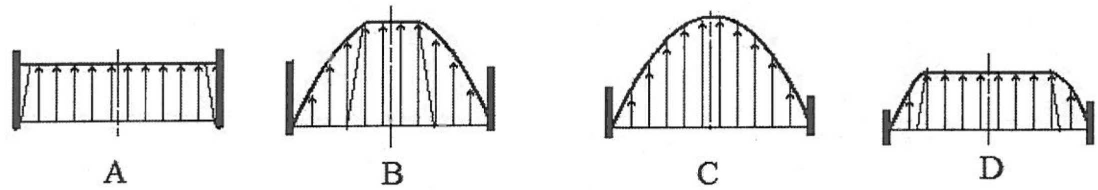
A large slab of copper is initially at a uniform temperature of 90°C. Its surface temperature is suddenly lowered to 30°C. Calculate the heat-transfer rate through a plane 7.5 cm from the surface at a time of 10s after the surface temperature is lowered to 30°C. $k_{cu} = 400$W/(m.°C) ; h = 512W/(m².°C) It could be useful (but not essential) to use the Heislaar charts supplied to find the answer. $\alpha = 11.23 \times 10^{-5}$ m²/s

[15]

QUESTION 4 Flow Regimes

4.

4.1. The sketches below represent different flow profiles of fluid in a conduit (hose). Answer the following questions on related to this: -



[6]

4

4.1.1 Which diagram represents fully developed laminar flow?
4.1.2 Which drawing represents fully developed turbulent flow?
4.1.3 Which drawings represent transient flow conditions?

4.2 Explain in your own words the physical difference between laminar and turbulent flow.

[5]

4.3 Can one have a flow regime where both Newtonian (laminar) and non-Newtonian (turbulent) flow can occur? Explain.

[5]
[16]

QUESTION 5 IGNORE THE EFFECTS OF RADIATION IN THIS EXERCISE!

5 A concrete wall is exposed on one side to heat flux of $2600 W/m^2$ (i.e. that is what enters the wall). The wall is 30 cm thick and has an average value of thermal conductivity of 0.8W/m°C.

5.1 Determine the temperature drop in the wall under steady state conditions (ΔT). *(7marks)*

5.2 If the other side of the wall is exposed to air at 32°C with a convection coefficient of $67 W/m^{2}{}^{\circ}C$, determine the wall surface temperatures (Both sides). *(7marks)*

[14]

QUESTION 6

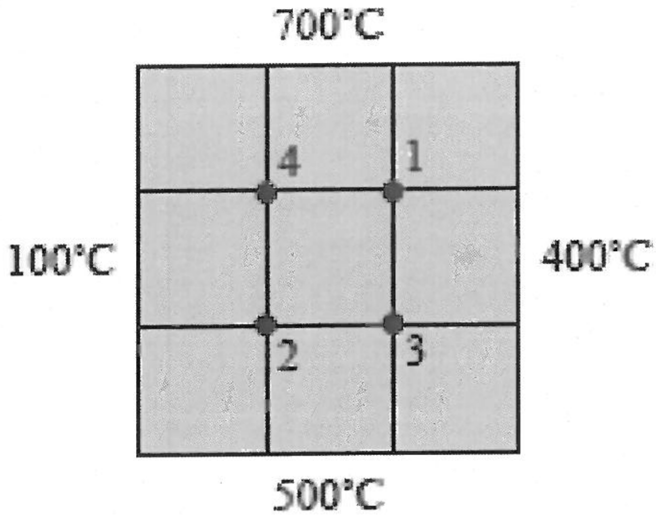
Air at 20°C and **1 atm** = 101.325 bar flows over the surface of a flat piece of metal at a speed of 4 m/s. Calculate the boundary layer thickness at distances of 15 and 30 cm from the leading edge of the plate. Assume that the mass flow that enters the boundary layer between x = 15cm and x = 30cm is 0.0045 kg/s. The viscosity of air at 32°C is 1.95×10^{-5} kg/m-s. Assume unit depth in the z direction. The plate is heated to 60°C. Calculate the heat transferred in (a) the first 15cm of the metal plate and (b) the first

30cm of the metal plate. See Equations and data for helpful information in Appendices

[10]

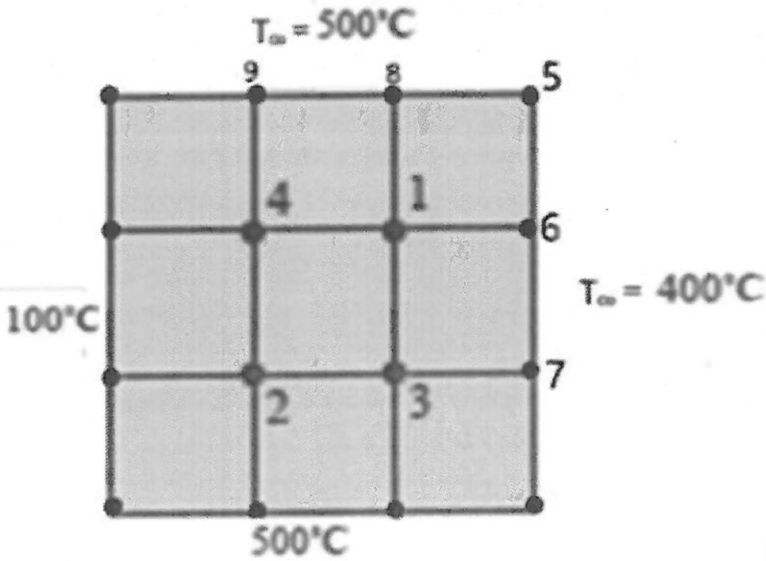
QUESTION 7

7.1 In the Figure provided giving the temperatures of the corresponding surfaces, calculate the temperatures at points 1, 2, 3, and 4 using the numerical method.



[10]

7.2 If in the following figure below, the top 500°C and right-hand side 400°C temperatures are of the convection environment to which the body is exposed to and the two remaining temperatures are the surfaces actual temperature (i.e. left-hand side 100°C and bottom 500°C) write out the equations and simplify them that can be used to calculate the temperatures at all nine numbered points. Leave out expressions for T_7 and T_8



[15]

[25]

Total Marks **[140]**

Appendix A "erf" Function values

Table The error function.

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

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.

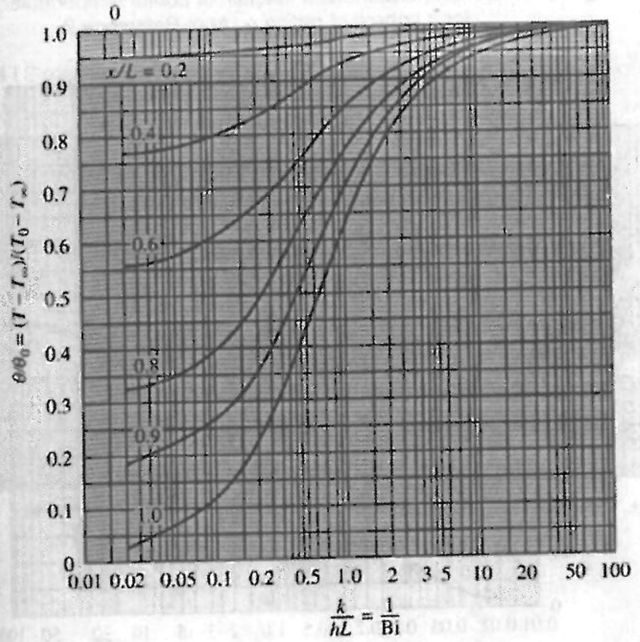
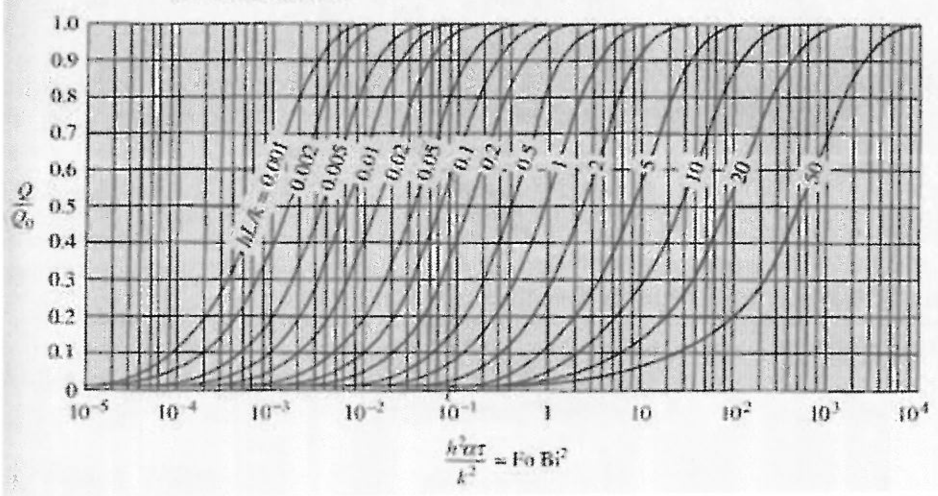


Figure 4-14 | Dimensionless heat loss Q/Q_0 of an infinite plane of thickness $2L$ with time, from Reference 6.



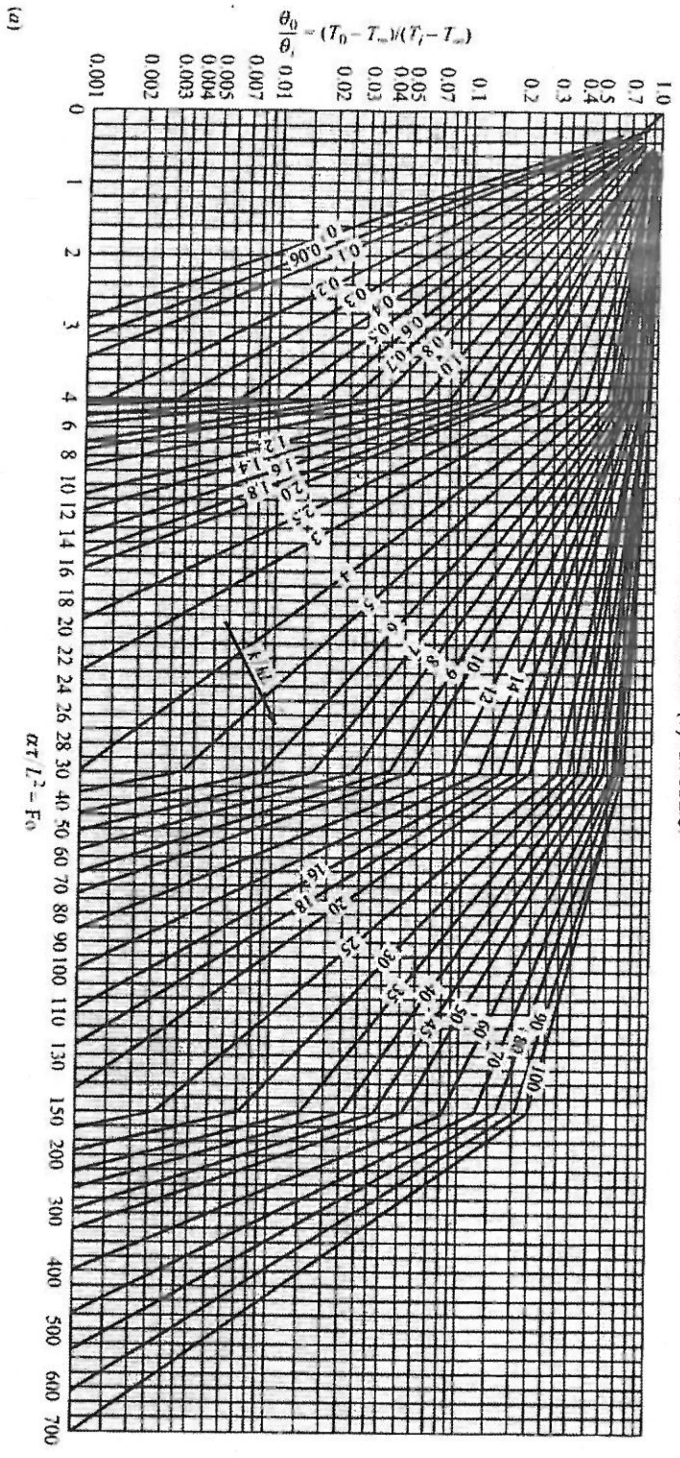


Figure 4-7 | Midplane temperature for an infinite plate of thickness $2L$: (*a*) full scale.

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

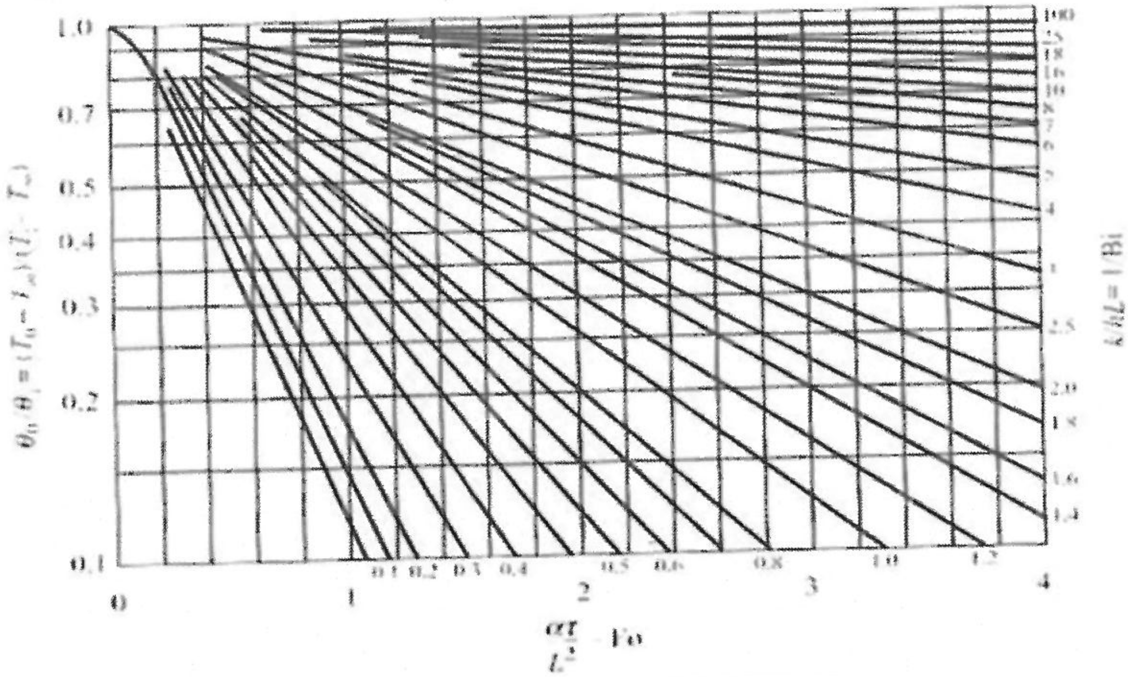


Figure 4-5 | Temperature distribution in the semi-infinite solid with convection boundary condition.

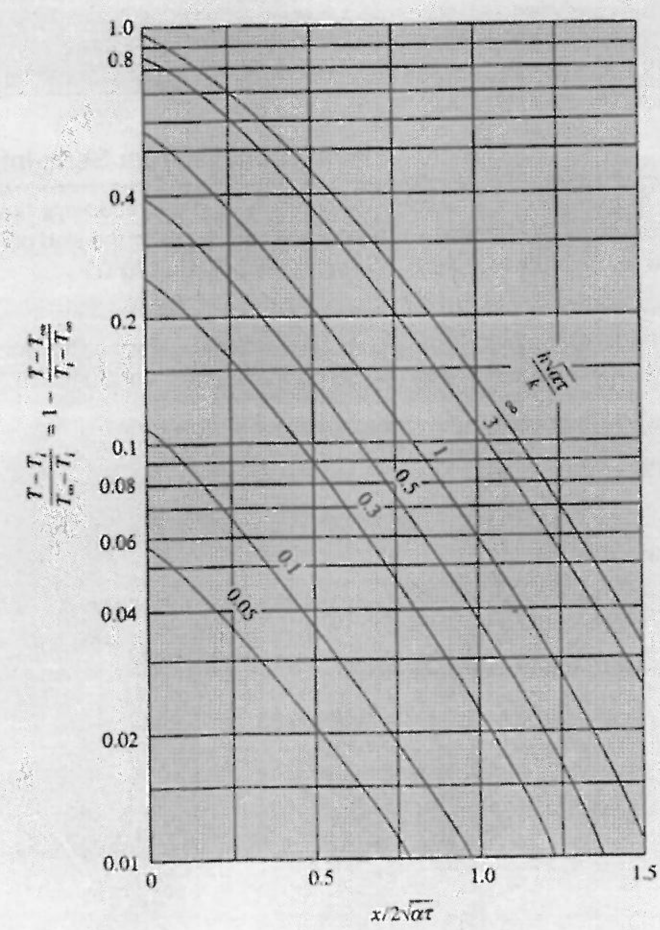


Table 3-2 | Summary of nodal formulas for finite-difference calculations. (Dashed lines indicate element volume.)†

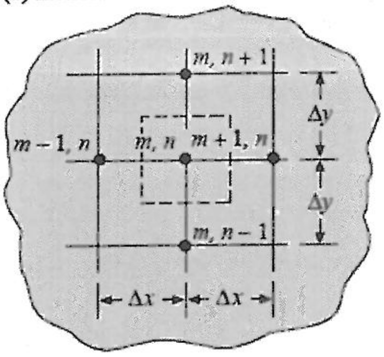
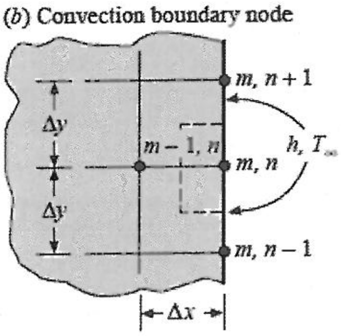
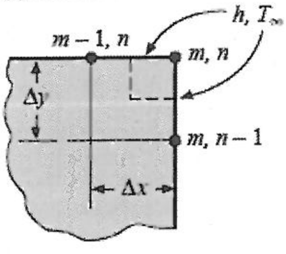
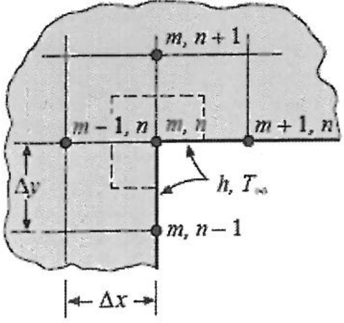
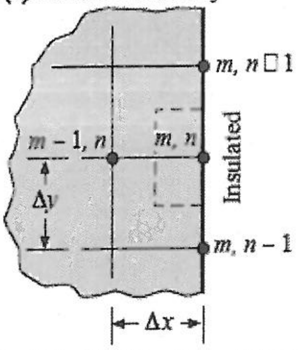
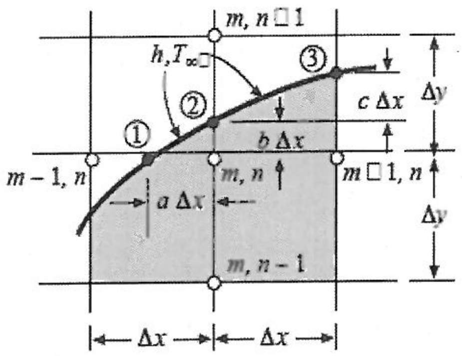
Physical situation	Nodal equation for equal increments in x and y (second equation in situation is in form for Gauss-Seidel iteration)
(*a*) Interior node 	$0 = T_{m+1,n} + T_{m,n+1} + T_{m-1,n} + T_{m,n-1} - 4T_{m,n}$ $T_{m,n} = (T_{m+1,n} + T_{m,n+1} + T_{m-1,n} + T_{m,n-1})/4$
(*b*) Convection boundary node 	$0 = \frac{h\Delta x}{k} T_\infty + \frac{1}{2}(2T_{m-1,n} + T_{m,n+1} + T_{m,n-1}) - \left(\frac{h\Delta x}{k} + 2\right) T_{m,n}$ $T_{m,n} = \frac{T_{m-1,n} + (T_{m,n+1} + T_{m,n-1})/2 + \text{Bi}\, T_\infty}{2 + \text{Bi}}$ $\text{Bi} = \frac{h\Delta x}{k}$
(*c*) Exterior corner with convection boundary 	$0 = 2\frac{h\Delta x}{k} T_\infty + (T_{m-1,n} + T_{m,n-1}) - 2\left(\frac{h\Delta x}{k} + 1\right) T_{m,n}$ $T_{m,n} = \frac{(T_{m-1,n} + T_{m,n-1})/2 + \text{Bi}\, T_\infty}{1 + \text{Bi}}$ $\text{Bi} = \frac{h\Delta x}{k}$
(*d*) Interior corner with convection boundary 	$0 = 2\frac{h\Delta x}{k} T_\infty + 2T_{m-1,n} + T_{m,n+1} + T_{m+1,n} + T_{m,n-1} - 2\left(3 + \frac{h\Delta x}{k}\right) T_{m,n}$ $T_{m,n} = \frac{\text{Bi}\, T_\infty + T_{m,n+1} + T_{m-1,n} + (T_{m+1,n} + T_{m,n-1})/2}{3 + \text{Bi}}$ $\text{Bi} = \frac{h\Delta x}{k}$

Table 3-2 | *(Continued)*.

Physical situation	Nodal equation for equal increments in x and y (second equation in situation is in form for Gauss-Seidel iteration)
(*e*) Insulated boundary	$0 = T_{m,n+1} + T_{m,n-1} + 2T_{m-1,n} - 4T_{m,n}$ $T_{m,n} = (T_{m,n+1} + T_{m,n-1} + 2T_{m-1,n})/4$



Physical situation	Nodal equation
(*f*) Interior node near curved boundary‡	$0 = \frac{2}{b(b+1)}T_2 + \frac{2}{a+1}T_{m+1,n} + \frac{2}{b+1}T_{m,n-1} + \frac{2}{a(a+1)}T_1 - 2\left(\frac{1}{a}+\frac{1}{b}\right)T_{m,n}$



Physical situation	Nodal equation
(*g*) Boundary node with convection along curved boundary—node 2 for (*f*) above§	$0 = \frac{b}{\sqrt{a^2+b^2}}T_1 + \frac{b}{\sqrt{c^2+1}}T_3 + \frac{a+1}{b}T_{m,n} + \frac{h\Delta x}{k}\left(\sqrt{c^2+1}+\sqrt{a^2+b^2}\right)T_\infty$ $-\left[\frac{b}{\sqrt{a^2+b^2}} + \frac{b}{\sqrt{c^2+1}} + \frac{a+1}{b} + \left(\sqrt{c^2+1}+\sqrt{a^2+b^2}\right)\frac{h\Delta x}{k}\right]T_2$

† Convection boundary may be converted to insulated surface by setting $h = 0$ (Bi = 0).
‡ This equation is obtained by multiplying the resistance by $4/(a+1)(b+1)$
§ This relation is obtained by dividing the resistance formulation by 2.