UNIVERSITY OF JOHANNESBURG

PROGRAM	: NATIONAL DIPLOMA *ENGINEERING METALLURGY*	
SUBJECT	: **HEAT & MASS TRANSFER II**	
CODE	: **HMR21-1**	
DATE	: SUMMER EXAMINATION 2015 9 NOVEMBER 2015	
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	: 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. A long, thin copper rod 5 mm in diameter is exposed to an environment at 20°C. The base temperature of the rod is 120°C. The heat-transfer coefficient between the rod and the environment is 20 $W/m^2.^\circ C$. Calculate the heat given up by the rod.

2. You had an 8 metre long by 5 metre wide steel plate 30mm thick delivered to your site and you have placed it in a very large heating device capable of maintaining the temperature of the whole plate at a constant temperature of 200°C. The heating device is removed and the surfaces of the whole plate is instantaneously (immediately) cooled to 100°C. How long does it takefor the temperature at a depth 8 mm to drop to 125°C?

3. If the 8 m by 5 m by 30mm thick plate mentioned above in question1.2 had instead been <u>copper</u>, under the same conditions what would the temperature have been at a depth of 8 mm from its surface in the exact same time of cooling as calculated for the steel in question 1.2 above? i.e. for example *(and this is not the real answer)* if the steel plate in question 1.2 above had taken 200 seconds to cool to 125°C then what would the copper plate temperature at 8 mm depth from the surface have been after 200 seconds.

4. In 300 seconds calculate how much heat is removed from the steel plate in question 1.2 above in the time that it would take for the temperature at a depth 3mm below the surface to reach 150°C

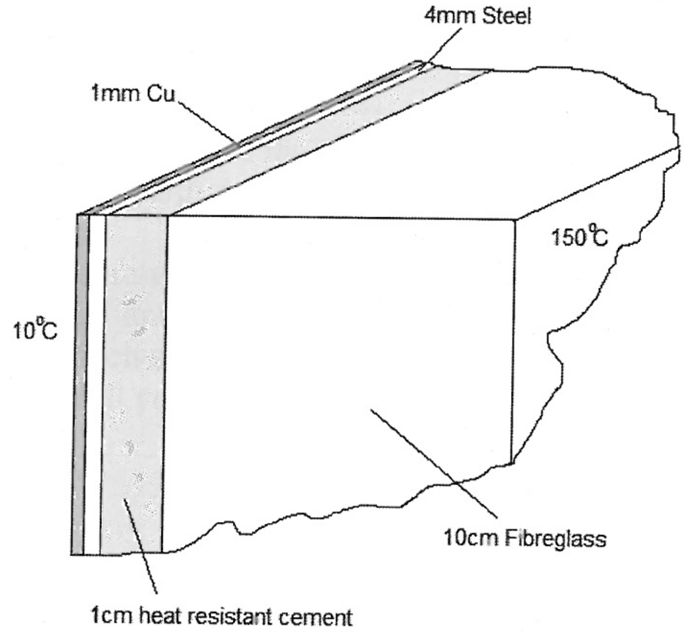
Assume α=8.4x10^{-5} m^2/s k_{steel} =50.0W/m.°C , k_{copper} = 400.0W/m.°C

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

[30]

QUESTION 2

A wall consists of a 1-mm layer of copper, a 4-mm layer of 1 % carbon steel, a 1-cm layer of heat resistant fibre cement sheet, and 10 cm of fiberglass blanket as shown in the sketch below. Calculate the overall heat-transfer coefficient for this arrangement. If the two outside surfaces are at 10 °C and 150°C, calculate each of the interface temperatures.



[15]

QUESTION 3

A 90 mm thick layer of mineral wool blocks is placed between two plates at 100°C and 200°C calculate the heat transfer across the mineral wool block layer.

[5]

QUESTION 4

As part of a magnetic field measuring device you want to bury a solid cylindrical rod of diameter 5cm in the ground (Earth/soil etc.). The rod is an electrical heating element that consumes electricity (energy) that is bought from the local

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

APPENDIX B
Equation and Data Sheet

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

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

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

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

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

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

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

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

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

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

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

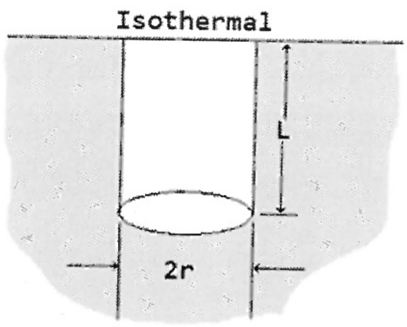
Table of relevant material data

Insulation Types and applications

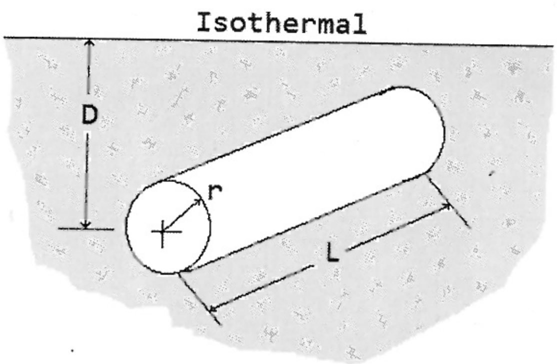
	Type	*Temperature range* °C	*Thermal Conductivity* (assume Linear function between limits)	*Density* Kg/m³	*Application*
1	Linde evacuated superinsulation	-240 to 1100	0.0015 to 0.72 *milliW/m °C**	Variable	Many
2	Urethane foam	-180 to 150	16 to 20 *milliW/m °C**	25 to 48	Hot and cold pipes
3	1% Carbon 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

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

Shape factors:

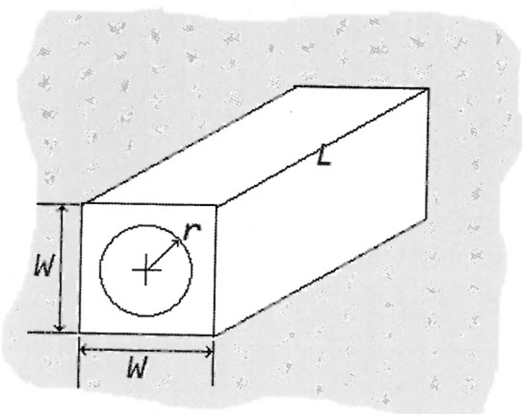


$$S = \frac{2\pi L}{\ln\left(2L/r\right)} \qquad L \gg 2r$$



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

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



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

$L \gg W$

Heislar and other charts

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

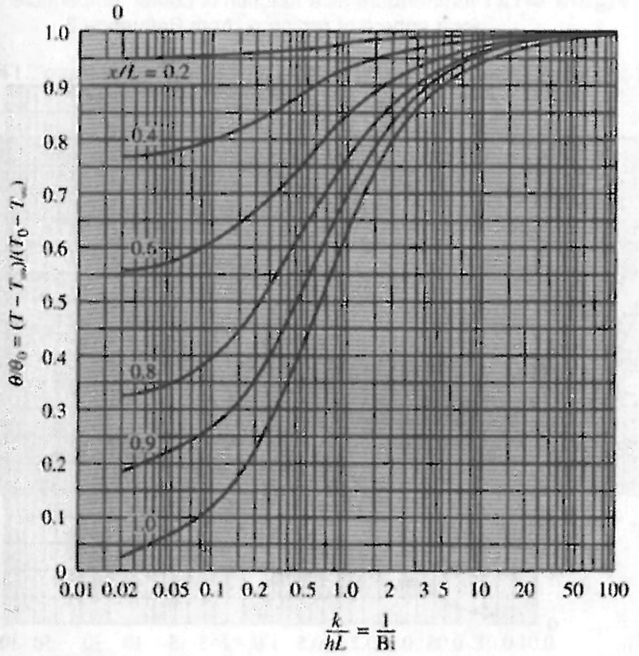


Figure 4-14 | Dimensionless heat loss Q/Q_0 of an infinite plane of thickness $2L$ with time, from Reference 6.

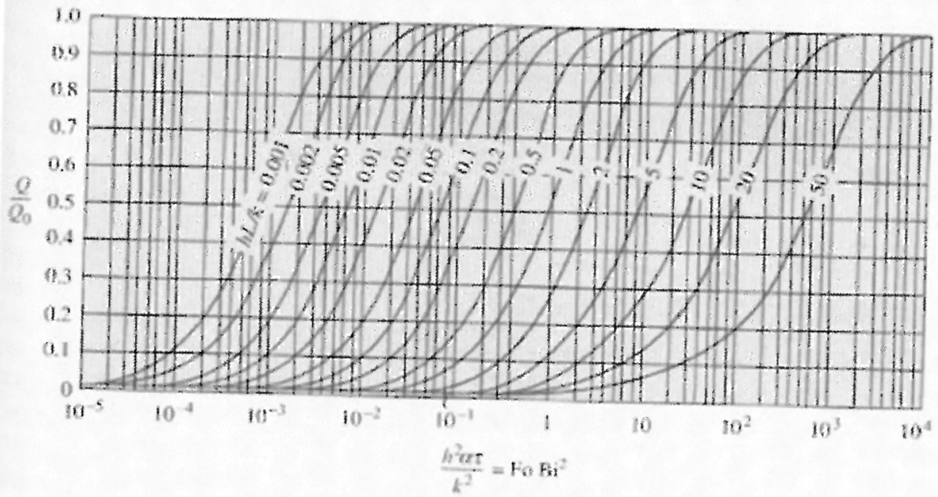
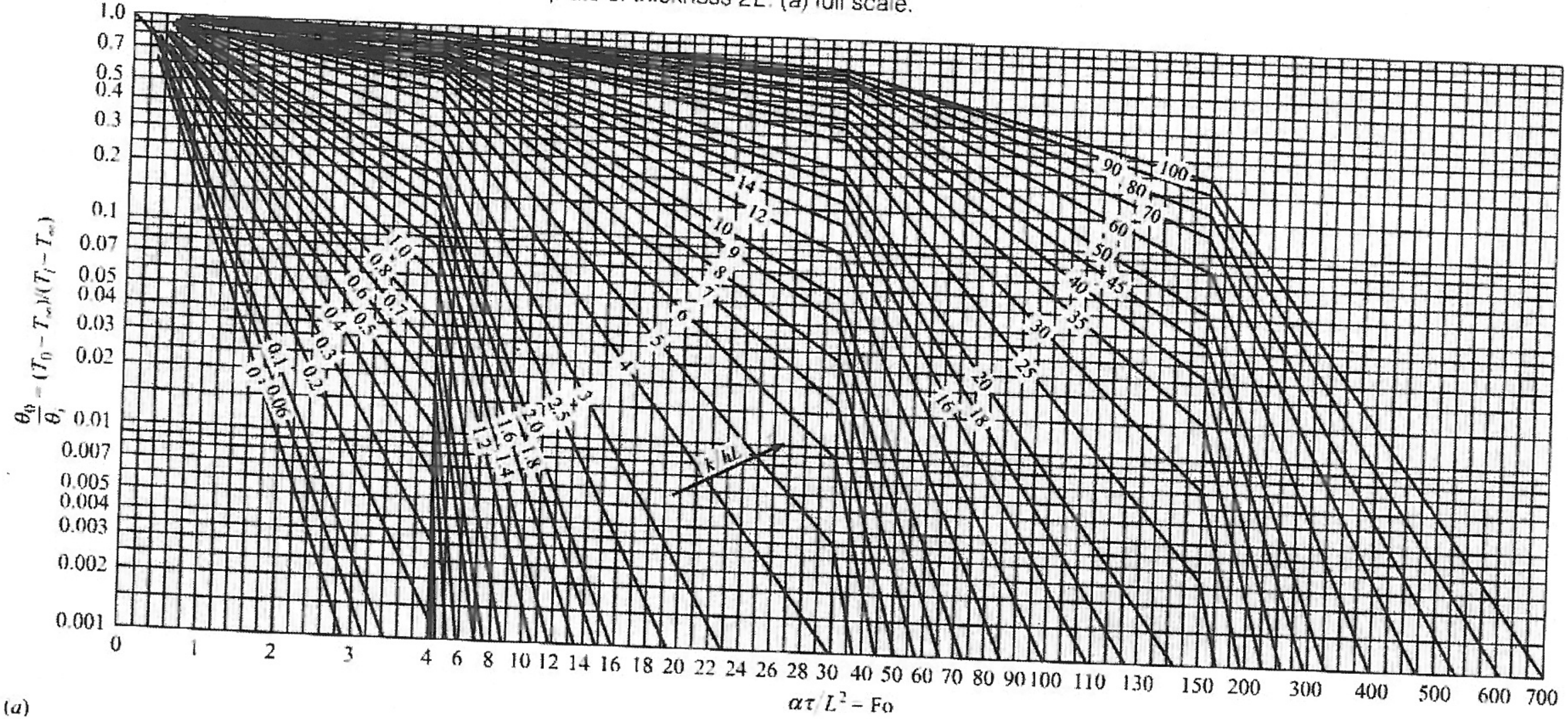


Figure 4-7 | Midplane temperature for an infinite plate of thickness $2L$: (*a*) full scale.



(*a*)

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

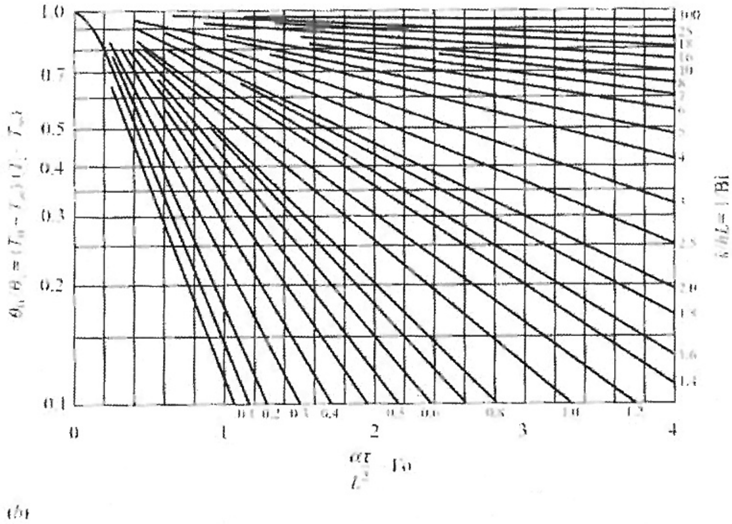


Figure 4-5 | Temperature distribution in the semi-infinite solid with convection boundary condition.