UNIVERSITY OF JOHANNESBURG

PROGRAM	:	B ENG TECH METALLURGY
SUBJECT	:	**HEAT & MASS TRANSFER II**
CODE	:	**HMTMTA2**
DATE	:	SSA EXAMINATION 19 JULY 2018
DURATION	:	08:00 - 11:00
WEIGHT	:	40 : 60
TOTAL MARKS	:	110

EXAMINER	:	MR GA COMBRINK	Sanso Number
MODERATOR	:	MR J M PROZZI	5113
NUMBER OF PAGES	:	10 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

A truncated cone 50 cm high is constructed of pure aluminium. The diameter at the top is 7.5 cm, and the diameter at the bottom is 12.5 cm. The lower surface is maintained at 93˚C; the upper surface, at 540˚C. The other surface is insulated. Assuming one dimensional heat flow, what is the rate of heat transfer in watts?

[10]

Question 2

A very large industrial continuously casting furnace has a composite wall that consists of three layers viz.

- namely an **outer** insulation layer of mineral wool, (this is the side facing the outside ambient air)
- a **central** structural element made from carbon steel and
- an **inner** fire brick layer (ceramic). (this is the side facing the fire inside the furnace)

The carbon steel layer that is **sandwiched** between the insulation and fire brick layers. The furnace inner wall temperature is at a constant 850°C. (note that the wall surface is at 850ºC) IGNORING ALL CONVECTION AND RADIATION HEAT TRANSFER MECHANISMS ANSWER THE FOLLOWING QUESTIONS: -

2.
   2.1. If the temperature on the outside of the liner is a constant 25ºC, what is the absolute amount of heat that is transferred through the lining? (Give your answer to the second decimal point only)
   2.2. What is the overall thermal resistance through the wall on a per m^2 basis?
   2.3. What is the temperature of the structural steel surfaces on both sides?

For this question use the following parameters: -

Material	Thermal Conductivity (W/(m.K))	Thickness of the layer (mm)
Carbon Steel (structural layer)	43	40
Mineral Wool (outer insulation layer)	0.038	40
Fire Brick (inside heat resistant layer)	2	60

[20]

Question 3

Convert the following *(to get the marks in addition to getting the value correct, your answer **MUST** give the units of the scale used in the correct place as is the recognized convention): -*

1. Minus 220°F to °C *(1 mark)*
2. 475°R to °F *(1 mark)*
3. 972°R to °C *(2 marks)*
4. Minus 480°F to °R *(1 marks)*
5. 16.84K to °C *(1 mark)*

[6]

Question 4

A 5.0-cm inside diameter pipe of infinite length is heated from the inside making the inside surface temperature to be to be at a constant temperature of 250°C, The wall thickness of the pipe is 3mm and it is made from 1% carbon steel. (see appendix B for information of k value). On the outer surface of the pipe air at 30°C is forced to blow over the pipe at a velocity of 50 m/s. The outer surface of the pipe is painted dark grey and it has an emissivity factor of 0.7. Write down the formula with all the values you can and then demonstrate how you would calculate the total heat loss from the pipe per unit length (Take note that no air passes through the pipe.). You don't have to do the actual calculation just explain after you have set up the formula how it would be done (briefly). Comment on this final equation so that I know what you are doing. For the air at 30°C blowing over the pipe surface at 50m/s take h = 180W/(m^2.°C) ; Stefan-Boltzman constant (σ) = 5.69 x 10^{-8} W/m^2.K^4 ; $k_{(1\% cs)}$ = 40W/(m °C)

TIP: This question involves you doing a heat (energy) balance using all three forms of heat transfer and then to solve for the outer surface temperature you may choose to solve it using a trial and error numerical method

[25]

Question 5

A wall 2 cm thick is to be constructed from material that has an average thermal conductivity of 1.3 W/(m.°C). The wall is to be insulated with material having an average thermal conductivity of 0.35W/(m.°C), so that the heat loss per square meter will not exceed 1830W. Assuming that the inner and outer surface temperatures of the insulated wall are 1300°C and 30°C, calculate the thickness of insulation required.

Convection heat transfer coefficient (system above) = 25W/(m^2.°C)
Conduction heat transfer coefficient (steel) = 43W/(m.°C)

[10]]

Question 6

6. Ignore the effect of radiation in this question: Calculate the thickness in millimetres of a solid wall: -
   6.1. Aluminium wall if the temperature difference over the wall is 30K and the heat transfer per unit area is 600 kW/m^2 (7 marks)
   6.2. What would have been the wall thickness under the same conditions had the wall material been copper instead. (the temperature gradient over this wall is still 30K and the heat transfer is still 600kW/m^2) (7 marks)
   6.3. Explain the why there is a difference in the wall thickness values. (3 marks)
   6.4. Which one of these two metals will you choose for a heat exchanger and explain your answer? (3 marks)

Take k_{al} = 205 W/(m.°C) and k_{Cu} =450 W/(m.°C): density Cu = 8900kg/m^3 and Aluminium = 2700 kg/m^3

[20]

Question 7

Draw a sketch representing the transition from laminar to fully developed turbulent flow of a fluid such as water over a flat surface. Label the sketch indicating the various flow regimes and also represent the two dimensional velocity profile and flow patterns at the various regimes.

[9]

Question 9

Heat Removal from Semi-Infinite Solid

A large slab of aluminum 25mm thick is at a uniform temperature of 250°C. It is suddenly exposed to a cold environment that **immediately cools its surface temperature** to 123°C. What is the total heat removed from the slab per unit surface area when the temperature at a depth of 8 mm has dropped to 143°C?

α=8.4x10^{-5} m^2/s k_{Al} =215W/(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]

Total Marks [112]

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

Metal	Properties at 20°C: ρ kg/m³	c_p kJ/kg·°C	k W/m·°C	$\alpha \times 10^5$ m²/s	Thermal conductivity k, W/m·°C: −100°C −148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Aluminum:														
Pure	2,707	0.896	204	8.418	215	202	206	215	228	249				
Iron:														
Pure	7,897	0.452	73	2.034	87	73	67	62	55	48	40	36	35	36
Wrought iron, 0.5% C	7,849	0.46	59	1.626		59	57	52	48	45	36	33	33	33
Steel (C max ≈ 1.5%):														
Carbon steel														
C ≈ 0.5%	7,833	0.465	54	1.474		55	52	48	45	42	35	31	29	31
1.0%	7,801	0.473	43	1.172		43	43	42	40	36	33	29	28	29
1.5%	7,753	0.486	36	0.970		36	36	36	35	33	31	28	28	29
Copper:														
Pure	8,954	0.3831	386	11.234	407	386	379	374	369	363	353			
Aluminum bronze 95% Cu, 5% Al	8,666	0.410	83	2.330										

Stefan-Boltzman constant (σ) is 5.669 x 10^{-8} W/m².K⁴

Shape factors: for a box shape

$$\text{Walls } S = \frac{A}{L}$$

$$\text{Corners } S = 0.15L \qquad q = kS\Delta T$$

$$\text{Edges } S = 0.54D$$

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

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

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

General Equations

$$R = \frac{1}{hA}$$

$$R = \frac{\Delta X}{kA}$$

$$q = UA\Delta T = \frac{\Delta T}{R_{overall}}$$

If for any question the following parameters are not given then any appropriate value of these following parameters can be used but record what you have assumed on your answering script before you use the parameter in a specific question. Do not use these parameters when the real parameter is provided to you in the question.

$r_o = 2.5cm$
$h = 525\ W/m^2.°C$
$k = 215\ W/m°C$
$\tau = 1\ minute$
$\rho = 2700kg/m^3$
$\alpha = 8.4 \times 10^{-5}\ m^2/s$
$c = 0.9\ kJ/kg.°C$

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

$$\frac{\theta}{\theta_i} = \frac{\theta_o}{\theta_i}\frac{\theta}{\theta_o}$$

Appendix C : Heislar & Other Charts

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

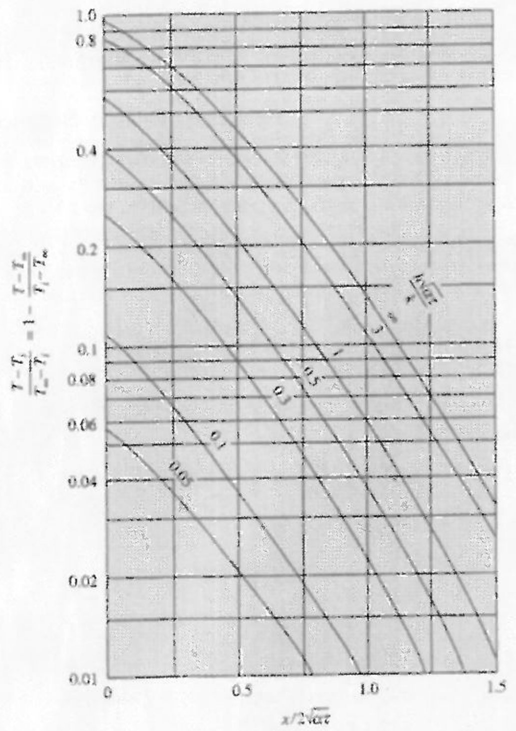
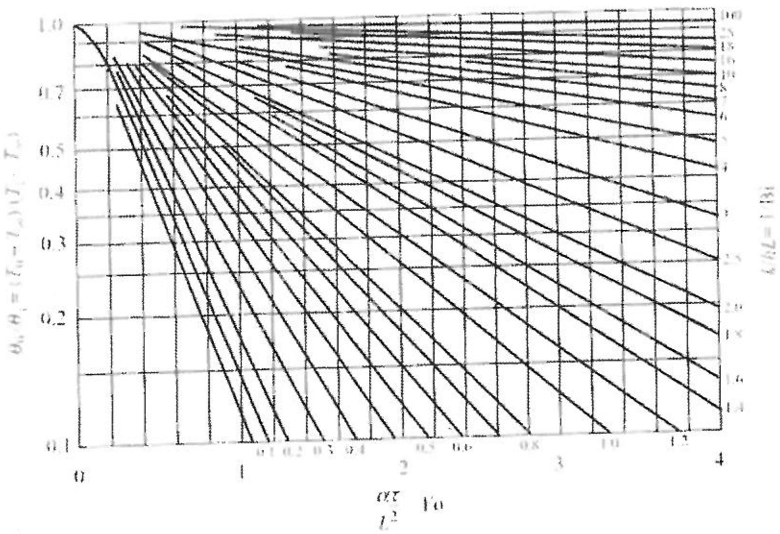


Figure 4-7 | (Continued). (b) expanded scale for 0 < Fo < 4, from Reference 2.



(b)

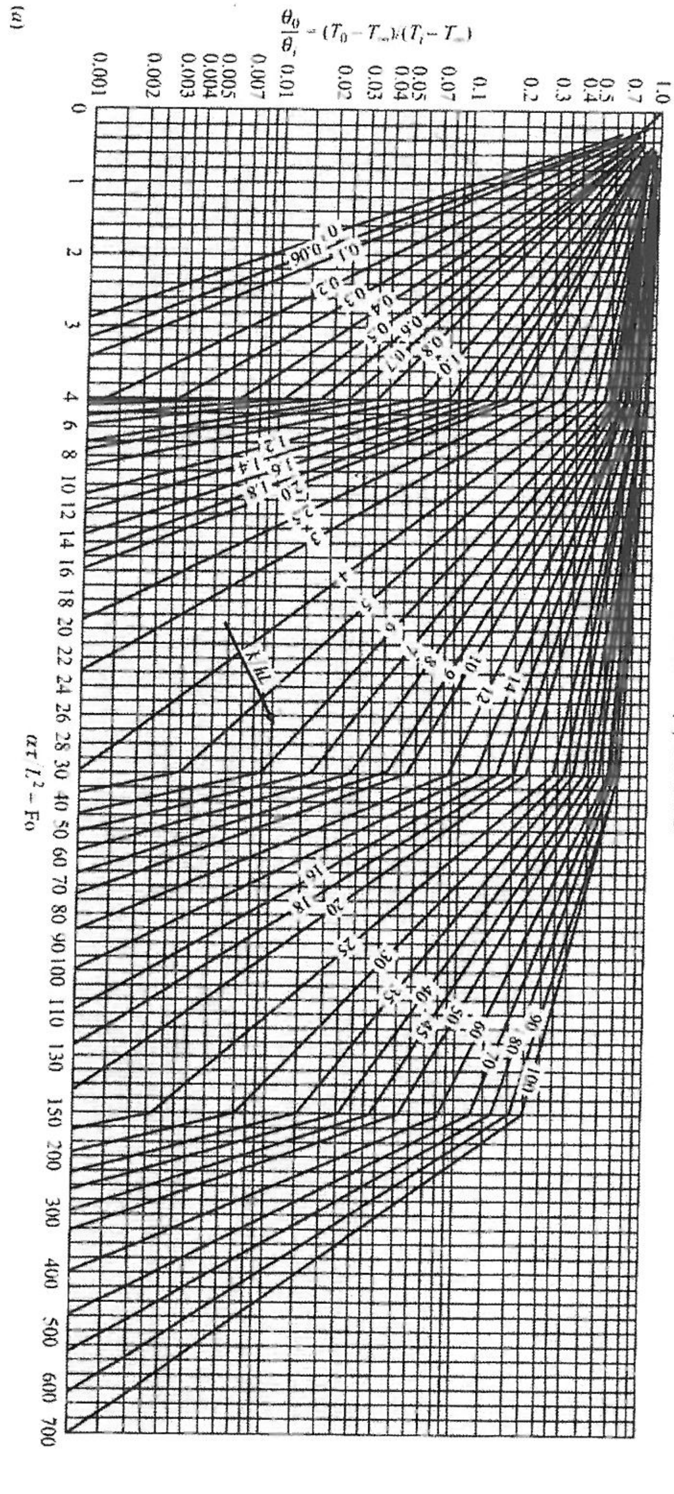


Figure 4-7 | Midplane temperature for an infinite plate of thickness 2L: (a) full scale.

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

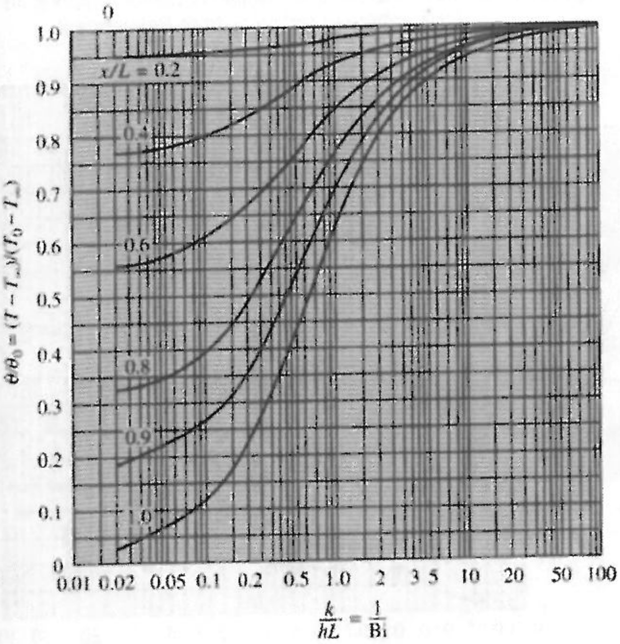


Figure 4-14 | Dimensionless heat loss Q/Q_0 of an infinite plane of thickness 2*L* with time, from Reference 6.