UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, APRIL 18, 2001, 14:00 – 16:30

MMS220S – HEAT AND MASS TRANSFER IN METALLURGICAL PROCESSES

EXAMINER: T. UTIGARD

NOTE:
1. Only non-printing calculators may be used
2. Total of 5 pages
3. ANSWER ALL SIX(6) QUESTIONS

Problem No. 1(20 marks): A reactor with an inside gas temperature of 1225 °C has a wall consisting of a) 10 cm thick refractory brick, b) 15 cm of insulation and c) 0.75 cm thick steel shell. The outside air temperature is 15 °C. The thermal conductivities are: refractory brick k = 2.5 W/m·K; insulation k = 0.25 W/m·K; steel shell k = 40 W/m·K; Heat transfer coefficients: Inside h = 25 W/m^2K; Outside h = 10 W/m^2K.

a) What is the total heat loss(kW) when the total reactor wall area equals 120 m^2 ?
b) What is the temperature half way through the insulation ?
c) Discuss the purposes of the various materials of construction used in building the reactor wall
d) Discuss various ways you could decrease the temperature of the outside surface of the steel shell while maintaining the inside gas temperature at 1225 °C.

Problem No. 2(10 marks): After heat treatment of 5.0 cm diameter solid copper spheres in a furnace at 300 °C, the spheres are taken out of the furnace and cooled in room temperature(20 °C) air. The average heat transfer coefficient is 15.0 W/m^2K.

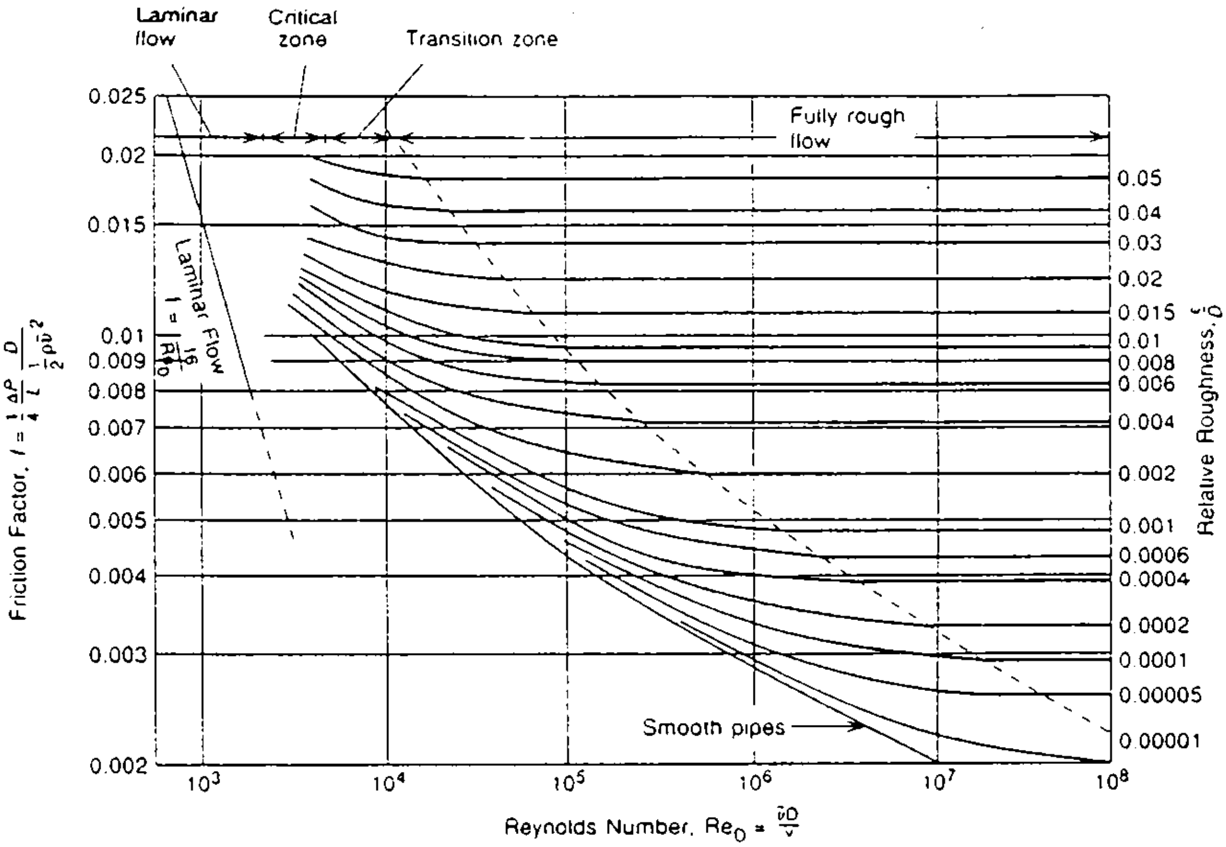
a) Ignoring radiation heat losses, calculate how long(minutes) it takes before the copper spheres reach 50 °C.

Data: The properties of copper are: c_p = 390 J/kg·°C, k = 385 W/m·°C and ρ = 8900 kg/m^3.

Problem No. 3(20 marks): A 15 km long steel pipeline with an inner diameter of 35 cm delivers 30,000 m^3 of gasoline per day. The end of the pipeline is 50 m below the starting point of the pipeline. The density of the gasoline is 770 kg/m^3 and its viscosity is $7 \cdot 10^{-4}$ kg/m·s. The relative roughness of the inside of the pipe is 0.0002.

a) Determine the Reynolds number
b) Determine the friction factor
c) Determine the total power(kW) required to pump this gasoline.
d) For an energy cost of 7.5 cents per kWHr, what is the pumping cost per 1000 kg of gasoline.

Data: See attached friction factor chart on next page.



Laminar flow
Critical zone
Transition zone
Fully rough flow
Laminar Flow $f = \frac{16}{Re_D}$
Smooth pipes
Friction Factor, $f = \frac{1}{4}\frac{\Delta P}{L}\frac{D}{\frac{1}{2}\rho\bar{v}^2}$
0.025
0.02
0.015
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
Relative Roughness, $\frac{\epsilon}{D}$
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0006
0.0004
0.0002
0.0001
0.00005
0.00001
10^3
10^4
10^5
10^6
10^7
10^8
Reynolds Number, $Re_D = \frac{\bar{v}D}{\nu}$

Problem No. 4(20 marks): Air at 10 °C flows over a 2.0 m long and 1.5 m wide flat plate(30 °C) at a velocity of 10.0 m/s.

a) draw a schematics on how the boundary layer develops along the length of the plate
b) at which location does the transition from laminar to turbulent occur
c) draw a schematic on how the air-plate heat transfer coefficient varies along the length of the plate?
d) Determine the overall heat loss(W) from the plate

Table of properties of air

Temp(K)	Density (kg/m^3)	C_p (kJ/kg°C)	Viscosity (kg/m·s)	K (W/m.°C)
250	1.413	1.005	1.60×10^{-5}	0.022
300	1.177	1.006	1.85×10^{-5}	0.026
350	0.998	1.009	2.08×10^{-5}	0.030

Various heat transfer coefficient correlations for forced convection.

Situation	**Conditions**	**Nu = h·D/k; Pipe** **Nu = h·L/k: Plate, Ave.** **Nu = h·x/k: Plate, Local**
Pipe - Laminar	q = constant T_s = constant	4.36 3.66
Pipe/non-circular ducts; Turbulent	$T_{wall} > T_{fluid}$ $T_{wall} < T_{fluid}$	$0.023\cdot Re^{0.8}\cdot Pr^{0.4}$ $0.023\cdot Re^{0.8}\cdot Pr^{0.3}$
Flat plate - Laminar (Re < $3\cdot10^5$)	Local(x); 0.6<Pr<50 Average(L); 0.6<Pr<50 q = constant	$0.332\cdot Re(x)^{0.5}\cdot Pr^{1/3}$ $0.664\cdot Re(L)^{0.5}\cdot Pr^{1/3}$ $0.453\cdot Re(x)^{0.5}\cdot Pr^{1/3}$
Flat Plate - Turbulent $5\cdot10^5$< Re <10^8	Local(x); 0.6<Pr<60 Average(L); Re> $5\cdot10^7$ q = constant	$0.0296\cdot Re(x)^{0.8}\cdot Pr^{1/3}$ $0.037\cdot Re(L)^{0.8}\cdot Pr^{1/3}$ $0.0308\cdot Re(x)^{0.8}\cdot Pr^{1/3}$

$$Nu_{ave}(turb.) = (0.037 \cdot Re_L^{0.8} - 871) \cdot Pr^{1/3}$$

Problem No. 5(20 marks): A wide flat sand beach on a sunny day is exposed to 900 W/m^2 of radiation from the sun. The absorptivity of this radiation is 0.3. The back-ground sky temperature is –30 °C. The surrounding air temperature is 20 °C with a heat transfer coefficient of 8.0 W/m^2K. The emissivity of the sand for room temperature radiation is 0.8.

a) Describe how thermal radiation from a surface varies as the surface temperature increases. What changes take place?

b) Determine the temperature of the surface of the sand on the beach

Stefan Boltzmann Constant: $\sigma = 5.67\times10^{-8}$ W/m^2K^4

Problem No. 6(10 marks): At 25 °C, a 1.5 mm thick plastic membrane is separating a hydrogen(H_2) gas at 5 atm from a hydrogen gas at 0.1 atm. The diffusion coefficient of hydrogen in the plastic is $8.7\cdot10^{-8}$ m^2/s and the solubility of hydrogen in the plastic is 1.5 $mol/m^3\cdot atm$.

a) Calculate the molar flux of hydrogen(mol/m^2s) through the membrane.