PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Midterm Examination: Semester II | Academic Year : 2006

Date : 19 December 2006 | Time : 9.00 - 12.00

Subject : 230 - 392 Basic Chemical Engineering II | Room : R300

Student Name: .... Code : ....

Number of questions : 4

Time : 3 hours

Total marks : 70

Books and notes are not allowed

Calculators and writing in pencil are allowed.

Question	Full Marks	Marks Received
1	15	
2	15	
3	15	
4	25	
Total	70	

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

Student Name: .... Code : ....

1. A food cold storage room is to be built of an inner layer of 19.1 mm of pine wood, a middle layer of cork board, and an outer layer of 50.8 mm of concrete. The inside wall surface temperature is -17.8 °C and the outside surface temperature is 29.4 °C at the outer concrete surface. The mean conductivities are for pine wood, 0.151; cork, 0.0433; and concrete, 0.762 W/m.K. The total inside surface area of the room is 39 m^2. What thickness of cork board is needed to keep the heat loss to 586 watt?

   Note: Conduction equations for composite wall are:

$$q = -\frac{kA}{\Delta x}(T_2 - T_1), \qquad R_A = \frac{\Delta x_A}{k_A A}, \qquad q = \frac{\Delta T_{overall}}{\Sigma R_{th}}$$

   R_A = thermal resistance of material A, °C/w

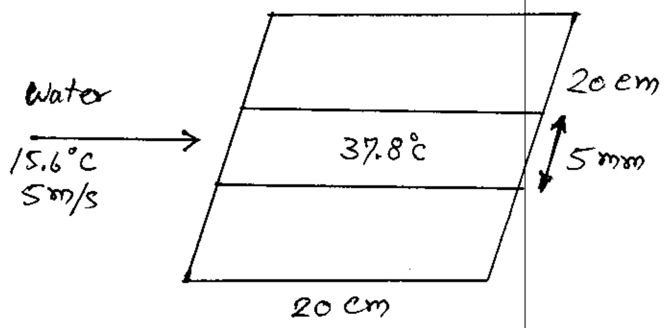
   R_{th} = thermal resistance, °C/w

(15 marks)

Answer to Q1.

Student Name: .... Code : ....

2. Water at 15.6 °C flows across a 20-cm-square plate with a velocity of 5m/s, A thin film, 5 mm. wide, is placed on the plate at the leading edge. If the film is heated to a constant temperature of 37.8°C, calculate the heat lost from the film.



Note:

When heating starts at x_0 away from leading edge,

$$N_{ux} = 0.332\,Pr^{1/3}\,Re_x^{1/2}\left[1-\left(\frac{x_0}{x}\right)^{3/4}\right]^{-1/3}$$

When heating starts at leading edge,

$$N_{ux} = 0.332\,Pr^{1/3}\,Re_x^{1/2}$$

film temperature, $T_f = \dfrac{T_w + T_\infty}{2}$

average h, $\bar{h} = \dfrac{\int_0^L h_x dx}{\int_0^L dx} = 2h_{x=L}$, average Nu_L, $\overline{Nu}_L = \dfrac{\bar{h}L}{k} = 2Nu_{x=L}$

$$Pr = \frac{\nu}{\alpha} = \frac{\mu/\rho}{k/\rho C_p} = \frac{C_p\mu}{k}, \qquad \nu = \frac{\mu}{\rho}$$

$$N_{ux} = \frac{h_x x}{k}, \qquad Re_x = \frac{\rho u_\infty x}{\mu}, \qquad Re_x = \frac{u_\infty x}{\nu}$$

(15 marks)

Student Name: .... Code : ....

3. Air at 1400 kPa enters a tube 7.5 cm in diameter and 3 m long at a rate of 0.5 kg/s. The tube wall is maintained at an average temperature of 500 K. The average air temperature in the tube is 550 K. Estimate the decrease in temperature of the air as it passes through the tube.

Note:

$$Re_d = \frac{\rho u_\infty d}{\mu}, \qquad Re_d = \frac{u_\infty d}{\nu}$$

for laminar flow in tube, $Nu_d = 1.86 (Re_d Pr)^{1/3} \left(\frac{d}{L}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$

for turbulent flow in tube, $Nu_d = 0.023\, Re_d^{0.8} Pr^n$ n = 0.4 for heating

n = 0.3 for cooling

(15 marks)

Answer to Q3.

Student Name: .... Code : ....

4. A shell-and-tube heat exchanger with one shell pass and two tubes passes is used to heat water (c_p=4.174 kJ/kg.°C) in the shell side from 27°C to 45°C. Hot engine oil (c_p=2.136 kJ/kg.°C) at the rate of 4 kg/s is used as counter flow in the tube sides to supply the heat and enters the exchanger at 90°C and leaves at 50°C. The average velocity of engine oil is 0.3 m/s. The heat transfer coefficient ,h_o for water is 850 $W/m^2.°C$. The total fouling factor is 0.0007 $m^2.°C/W$. The steel tubes are with configuration D_o = 0.019 m, D_i = 0.015 m and k = 54 W/m. °C. Tube length for the exchanger is 2.5 m. For engine oil it can be assumed that $\mu = \mu_w$.

Properties of engine oil are provided in the table. Note that $\nu = \frac{\mu}{\rho}$

a) Calculate the heat transfer coefficient, h_i for engine oil in $W/m^2.°C$.

b) Calculate the overall heat-transfer coefficient based on tube outside area, U_o in $W/m^2.°C$. This part of calculation can be based on 1 meter tube length.

c) Calculate the surface area of the heat exchanger.

Note: $$Re_d = \frac{u_\infty d}{\nu}$$

Overall heat transfer coefficient based on outside area is given by

$$U_o = \frac{1}{A_o\left(\frac{1}{h_i A_i} + \frac{\ln(r_o/r_i)}{2\pi k L} + \frac{1}{h_o A_o} + R_f\right)}$$

For multi shell passes and tube passes, $q = UAF\Delta T_m$

Where F is correction factor and ΔT_m is log mean temperature difference

The laminar and turbulent flow equations have been given in question 3.

(25 marks)

Table Properties of water (saturated liquid).†

Note: $Gr_x\,Pr = \left(\frac{g\beta\rho^2 c_p}{\mu k}\right) x^3 \Delta T$

°F	°C	c_p kJ/kg · °C	ρ kg/m³	μ kg/m · s	k W/m · °C	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$ 1/m³ · °C
32	0	4.225	999.8	1.79×10^{-3}	0.566	13.25	
40	4.44	4.208	999.8	1.55	0.575	11.35	1.91×10^{9}
50	10	4.195	999.2	1.31	0.585	9.40	6.34×10^{9}
60	15.56	4.186	998.6	1.12	0.595	7.88	1.08×10^{10}
70	21.11	4.179	997.4	9.8×10^{-4}	0.604	6.78	1.46×10^{10}
80	26.67	4.179	995.8	8.6	0.614	5.85	1.91×10^{10}
90	32.22	4.174	994.9	7.65	0.623	5.12	2.48×10^{10}
100	37.78	4.174	993.0	6.82	0.630	4.53	3.3×10^{10}
110	43.33	4.174	990.6	6.16	0.637	4.04	4.19×10^{10}
120	48.89	4.174	988.8	5.62	0.644	3.64	4.89×10^{10}
130	54.44	4.179	985.7	5.13	0.649	3.30	5.66×10^{10}
140	60	4.179	983.3	4.71	0.654	3.01	6.48×10^{10}
150	65.55	4.183	980.3	4.3	0.659	2.73	7.62×10^{10}
160	71.11	4.186	977.3	4.01	0.665	2.53	8.84×10^{10}
170	76.67	4.191	973.7	3.72	0.668	2.33	9.85×10^{10}
180	82.22	4.195	970.2	3.47	0.673	2.16	1.09×10^{11}
190	87.78	4.199	966.7	3.27	0.675	2.03	
200	93.33	4.204	963.2	3.06	0.678	1.90	
220	104.4	4.216	955.1	2.67	0.684	1.66	
240	115.6	4.229	946.7	2.44	0.685	1.51	
260	126.7	4.250	937.2	2.19	0.685	1.36	
280	137.8	4.271	928.1	1.98	0.685	1.24	
300	148.9	4.296	918.0	1.86	0.684	1.17	
350	176.7	4.371	890.4	1.57	0.677	1.02	
400	204.4	4.467	859.4	1.36	0.665	1.00	
450	232.2	4.585	825.7	1.20	0.646	0.85	
500	260	4.731	785.2	1.07	0.616	0.83	
550	287.7	5.024	735.5	9.51×10^{-5}			
600	315.6	5.703	678.7	8.68			

Table Properties of air at atmospheric pressure.†

The values of μ, k, c_p, and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures

T, K	ρ kg/m³	c_p kJ/kg · °C	$\mu \times 10^5$ kg/m · s	$\nu \times 10^6$ m²/s	k W/m · °C	$\alpha \times 10^4$ m²/s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680
550	0.6423	1.0392	2.848	44.34	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.680
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.3	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06525	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702
1100	0.3204	1.160	4.44	138.6	0.0732	1.969	0.704
1200	0.2947	1.179	4.69	159.1	0.0782	2.251	0.707
1300	0.2707	1.197	4.93	182.1	0.0837	2.583	0.705
1400	0.2515	1.214	5.17	205.5	0.0891	2.920	0.705
1500	0.2355	1.230	5.40	229.1	0.0946	3.262	0.705
1600	0.2211	1.248	5.63	254.5	0.100	3.609	0.705
1700	0.2082	1.267	5.85	280.5	0.105	3.977	0.705
1800	0.1970	1.287	6.07	308.1	0.111	4.379	0.704
1900	0.1858	1.309	6.29	338.5	0.117	4.811	0.704
2000	0.1762	1.338	6.50	369.0	0.124	5.260	0.702
2100	0.1682	1.372	6.72	399.6	0.131	5.715	0.700
2200	0.1602	1.419	6.93	432.6	0.139	6.120	0.707
2300	0.1538	1.482	7.14	464.0	0.149	6.540	0.710
2400	0.1458	1.574	7.35	504.0	0.161	7.020	0.718
2500	0.1394	1.688	7.57	543.5	0.175	7.441	0.730

†From *Natl. Bur. Stand. (U.S.) Circ.* 564, 1955.

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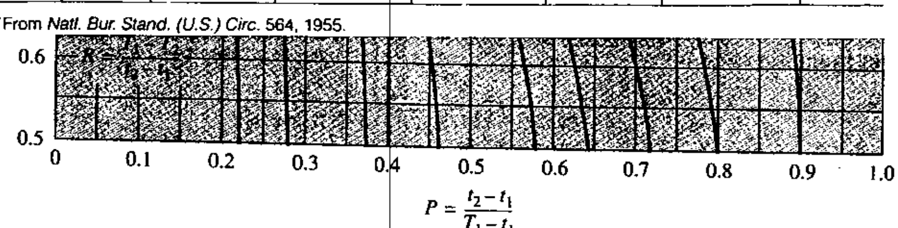

Table Properties of saturated liquids†

T, °C	ρ kg/m³	c_p kJ/kg·°C	ν, m²/s	k W/m·°C	α, m²/s	Pr	β, K⁻¹
			Glycerin, $C_3H_5(OH)_3$				
0	1,276.03	2.261	0.00831	0.282	0.983×10^{-7}	84.7×10^3	
10	1,270.11	2.319	0.00300	0.284	0.965	31.0	
20	1,264.02	2.386	0.00118	0.286	0.947	12.5	0.50×10^{-3}
30	1,258.09	2.445	0.00050	0.286	0.929	5.38	
40	1,252.01	2.512	0.00022	0.286	0.914	2.45	
50	1,244.96	2.583	0.00015	0.287	0.893	1.63	
			Ethylene glycol, $C_2H_4(OH)_2$				
0	1,130.75	2.294	7.53×10^{-6}	0.242	0.934×10^{-7}	615	
20	1,116.65	2.382	19.18	0.249	0.939	204	0.65×10^{-3}
40	1,101.43	2.474	8.69	0.256	0.939	93	
60	1,087.66	2.562	4.75	0.260	0.932	51	
80	1,077.56	2.650	2.98	0.261	0.921	32.4	
100	1,058.50	2.742	2.03	0.263	0.908	22.4	
			Engine oil (unused)				
0	899.12	1.796	0.00428	0.147	0.911×10^{-7}	47,100	
20	888.23	1.880	0.00090	0.145	0.872	10,400	0.70×10^{-3}
40	876.05	1.964	0.00024	0.144	0.834	2,870	
60	864.04	2.047	0.839×10^{-4}	0.140	0.800	1,050	
80	852.02	2.131	0.375	0.138	0.769	490	
100	840.01	2.219	0.203	0.137	0.738	276	
120	828.96	2.307	0.124	0.135	0.710	175	
140	816.94	2.395	0.080	0.133	0.686	116	
160	805.89	2.483	0.056	0.132	0.663	84	

Figure Correction-factor plot for exchanger with one shell pass and two, four, or any multiple of tube passes.