GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Quarter 1998

Heat Transfer
EXAM AREA

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Assigned Number (DO NOT SIGN YOUR NAME)

- **Please sign your name on the back of this page—**

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Ph.D. Qualifying Exam
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1. A 2 cm ice cube sits in a refrigerator at 10°C on a shelf of small diameter aluminum rods or wires. These aluminum wires are each 3 mm in diameter, the thermal conductivity of aluminum is approximately 200 W/m-K, and the average convective heat transfer coefficient between the wires and the air is 20 W/m^2-°C. If the value of h_{fs} is 330 kJ/kg and the density of ice is 900 kg/m^3, estimate in mm/min how rapidly the ice cube melts through the wires.

2. The tube bundle in a condenser is made up of tubes of inside diameter d_i and length L. It is recognized that the condensing heat transfer coefficient is very high, causing the tube wall temperature to be held at T_s. The mean temperature of the cooling water entering and leaving are T_i and T_e, respectively, and $\dot{m}$ is the mass flow rate.

a. Consider a differential length dx in the pipe section and develop the governing differential equation that describes the temperature distribution for this problem. State any assumptions you made in such a development.

b. Demonstrate that the solution to this differential equation is:

$$\frac{T_s - T_e}{T_s - T_i} = \exp\left[-(hA)/(\dot{m}c_p)\right]; \quad A = \pi d_i L;$$

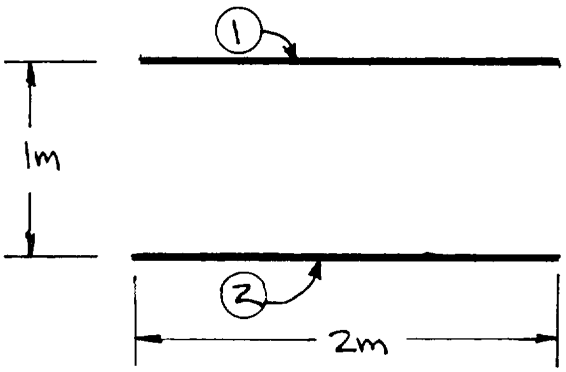
h is inside heat transfer coefficient and c_p is specific heat of the water.

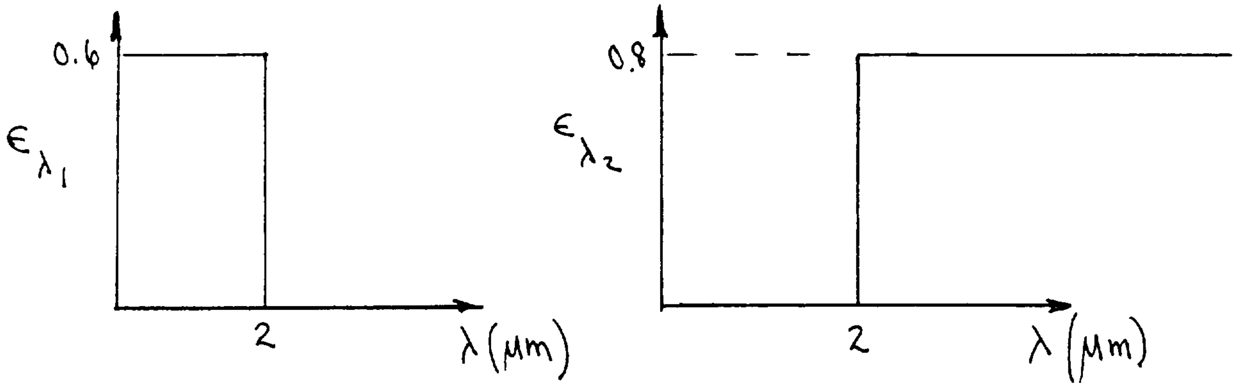
c. Draw the plausible temperature profile. Suggest a plausible heat transfer correlation for this problem.

d. Can you think of other problems which may have same characteristic solution?

e. An engineer claims that by doubling the number of tubes and mass flow rate but reducing the length to L/2 (total surface area for heat transfer being same), we can improve the heat transfer rate. Quantitatively demonstrate this thought.

3. Two diffuse, flat plates are placed in a vacuum and oriented parallel to each other as shown in the sketch. The plates are infinitely long in the direction into the figure. The surfaces have monochromatic emissivities shown in the figures below. The surfaces are isothermal at $T_1 = 3000\ K$, $T_2 = 4000\ K$ and the surroundings are at 0K.





Calculate the following information:

a) the total emissivity of surface 1
b) the total emissivity of surface 2
c) the shape factor F_{12}
d) the rate at which emitted radiant energy per unit length of surface 1 will arrive at the surroundings
e) the rate at which emitted radiant energy per unit length of surface 2 will arrive at the surroundings
f) the net amount of energy per unit length that must be removed from surface 1 to maintain its temperature
g) the net amount of energy per unit length that must be added to surface 2 to maintain its temperature

Table A-5 Blackbody functions *(Continued)*

Wavelength-temperature product λT		Blackbody hemispherical spectral emissive power divided by fifth power of temperature $e_{b\lambda}/T^5$		Blackbody fraction $F_{0-\lambda T}$	Difference between successive $F_{0-\lambda T}$ values ΔF
μm·K	μm·°R	W/(m²·μm·K⁵)	Btu/(h·ft²·μm·°R⁵)		
5300	9,540	634.59E-14	106.46E-15	0.66937	0.00565
5350	9,630	622.18E-14	104.38E-15	0.67491	0.00554
5400	9,720	610.00E-14	102.34E-15	0.68034	0.00543
5450	9,810	598.05E-14	100.33E-15	0.68566	0.00533
5500	9,900	586.33E-14	983.64E-16	0.69089	0.00522
5550	9,990	574.83E-14	964.36E-16	0.69600	0.00512
5600	10,080	563.56E-14	945.45E-16	0.70102	0.00502
5650	10,170	552.52E-14	926.92E-16	0.70594	0.00492
5700	10,260	541.69E-14	908.75E-16	0.71077	0.00482
5750	10,350	531.08E-14	890.95E-16	0.71550	0.00473
5800	10,440	520.68E-14	873.51E-16	0.72013	0.00463
5850	10,530	510.49E-14	856.42E-16	0.72468	0.00455
5900	10,620	500.51E-14	839.68E-16	0.72914	0.00446
5950	10,710	490.74E-14	823.28E-16	0.73351	0.00437
6000	10,800	481.17E-14	807.22E-16	0.73779	0.00428
6050	10,890	471.79E-14	791.50E-16	0.74199	0.00420
6100	10,980	462.62E-14	776.10E-16	0.74611	0.00412
6150	11,070	453.63E-14	761.02E-16	0.75015	0.00404
6200	11,160	444.83E-14	746.26E-16	0.75411	0.00396
6250	11,250	436.22E-14	731.81E-16	0.75800	0.00388
6300	11,340	427.79E-14	717.67E-16	0.76181	0.00381
6350	11,430	419.53E-14	703.82E-16	0.76554	0.00374
6400	11,520	411.45E-14	690.27E-16	0.76921	0.00366
6450	11,610	403.55E-14	677.00E-16	0.77280	0.00359
6500	11,700	395.81E-14	664.02E-16	0.77632	0.00352
6550	11,790	388.23E-14	651.31E-16	0.77978	0.00346
6600	11,880	380.82E-14	638.87E-16	0.78317	0.00339
6650	11,970	373.56E-14	626.70E-16	0.78650	0.00333
6700	12,060	366.46E-14	614.79E-16	0.78976	0.00326
6750	12,150	359.51E-14	603.13E-16	0.79296	0.00320
6800	12,240	352.71E-14	591.72E-16	0.79610	0.00314
6850	12,330	346.05E-14	580.55E-16	0.79918	0.00308
6900	12,420	339.54E-14	569.62E-16	0.80220	0.00302
6950	12,510	333.17E-14	558.93E-16	0.80517	0.00297
7000	12,600	326.93E-14	548.46E-16	0.80808	0.00291
7050	12,690	320.82E-14	538.22E-16	0.81093	0.00286
7100	12,780	314.85E-14	528.20E-16	0.81374	0.00280
7150	12,870	309.00E-14	518.39E-16	0.81649	0.00275
7200	12,960	303.28E-14	508.79E-16	0.81919	0.00270
7250	13,050	297.67E-14	499.39E-16	0.82183	0.00265
7300	13,140	292.19E-14	490.19E-16	0.82443	0.00260
7350	13,230	286.83E-14	481.19E-16	0.82699	0.00255
7400	13,320	281.57E-14	472.38E-16	0.82949	0.00251
7450	13,410	276.43E-14	463.75E-16	0.83195	0.00246
7500	13,500	271.40E-14	455.31E-16	0.83437	0.00242
7550	13,590	266.48E-14	447.05E-16	0.83674	0.00237
7600	13,680	261.65E-14	438.96E-16	0.83907	0.00233

Table A-5 *(Continued)*

Wavelength-temperature product λT		Blackbody hemispherical spectral emissive power divided by fifth power of temperature $e_{b\lambda}/T^5$		Blackbody fraction $F_{0-\lambda T}$	Difference between successive $F_{0-\lambda T}$ values ΔF
μm·K	μm·°R	W/(m²·μm·K⁵)	Btu/(h·ft²·μm·°R⁵)		
7650	13,770	256.93E-14	431.04E-16	0.84135	0.00229
7700	13,860	252.31E-14	423.29E-16	0.84360	0.00225
7750	13,950	247.79E-14	415.70E-16	0.84580	0.00220
7800	14,040	243.36E-14	408.27E-16	0.84797	0.00217
7850	14,130	239.03E-14	401.00E-16	0.85010	0.00213
7900	14,220	234.78E-14	393.87E-16	0.85219	0.00209
7950	14,310	230.62E-14	386.90E-16	0.85424	0.00205
8000	14,400	226.55E-14	380.07E-16	0.85625	0.00202
8050	14,490	222.57E-14	373.38E-16	0.85823	0.00198
8100	14,580	218.66E-14	366.84E-16	0.86018	0.00195
8150	14,670	214.84E-14	360.42E-16	0.86209	0.00191
8200	14,760	211.10E-14	354.14E-16	0.86397	0.00188
8250	14,850	207.43E-14	347.99E-16	0.86581	0.00185
8300	14,940	203.84E-14	341.96E-16	0.86762	0.00181
8350	15,030	200.32E-14	336.06E-16	0.86941	0.00178
8400	15,120	196.87E-14	330.28E-16	0.87116	0.00175
8450	15,210	193.50E-14	324.62E-16	0.87288	0.00172
8500	15,300	190.19E-14	319.07E-16	0.87457	0.00169
8550	15,390	186.95E-14	313.64E-16	0.87623	0.00166
8600	15,480	183.78E-14	308.31E-16	0.87787	0.00163
8650	15,570	180.67E-14	303.09E-16	0.87947	0.00161
8700	15,660	177.62E-14	297.98E-16	0.88105	0.00158
8750	15,750	174.63E-14	292.97E-16	0.88261	0.00155
8800	15,840	171.71E-14	288.06E-16	0.88413	0.00153
8850	15,930	168.84E-14	283.25E-16	0.88563	0.00150
8900	16,020	166.03E-14	278.54E-16	0.88711	0.00148
8950	16,110	163.28E-14	273.92E-16	0.88856	0.00145
9000	16,200	160.58E-14	269.39E-16	0.88999	0.00143
9050	16,290	157.93E-14	264.95E-16	0.89140	0.00140
9100	16,380	155.33E-14	260.59E-16	0.89278	0.00138
9150	16,470	152.79E-14	256.33E-16	0.89413	0.00136
9200	16,560	150.30E-14	252.15E-16	0.89547	0.00134
9250	16,650	147.85E-14	248.05E-16	0.89679	0.00131
9300	16,740	145.46E-14	244.02E-16	0.89808	0.00129
9350	16,830	143.11E-14	240.08E-16	0.89935	0.00127
9400	16,920	140.80E-14	236.22E-16	0.90060	0.00125
9450	17,010	138.54E-14	232.43E-16	0.90183	0.00123
9500	17,100	136.33E-14	228.71E-16	0.90305	0.00121
9550	17,190	134.15E-14	225.06E-16	0.90424	0.00119
9600	17,280	132.02E-14	221.49E-16	0.90541	0.00117
9650	17,370	129.93E-14	217.98E-16	0.90657	0.00115
9700	17,460	127.88E-14	214.54E-16	0.90770	0.00114
9750	17,550	125.87E-14	211.16E-16	0.90882	0.00112
9800	17,640	123.90E-14	207.85E-16	0.90992	0.00110
9850	17,730	121.96E-14	204.60E-16	0.91101	0.00108
9900	17,820	120.06E-14	201.42E-16	0.91207	0.00107

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