University of New Mexico
Mechanical Engineering
Spring 2013 PhD qualifying examination
Heat Transfer

Closed book. Formula sheet and calculator are allowed, but not cell phones, computers or any other wireless device.
Time allowed: 150 minutes.

Part 1: General knowledge questions (25 points)

1. Sometimes, one's bare hand feel "colder" when immersed in water at 5 °C than when exposed to air at -10 °C. Why?
   (a) There is an endothermic chemical reaction between water and oils in the skin.
   (b) The convection coefficient in water is much higher than in air, and as a result heat is removed from your hand at a much faster rate than in air
   (c) This is just a physiological reaction due to pores on your skin closing in water

   Answer:

2. Birds "fluff" their feathers while perching in cold weather because:
   (a) They tend to preen more in the winter because there is less to do
   (b) Feathers standing on end provide a thicker layer of still air with better insulating properties
   (c) they are trying to deter predators by looking bigger

   Answer:

3. Turbulent boundary layers are usually associated with higher convective heat transfer. In addition, one sees in general:
   (a) lower drag
   (b) higher drag
   (c) no change in drag

   Answer:

4. Weather reporters often cite temperatures associated with a "wind chill" factor. This can be explained as:
   (a) The temperature in still air which would produce the same amount of heat loss as in the windy condition
   (b) The difference between the wet and dry bulb temperatures in humid air
   (c) The actual air temperature due to cold winds from the Arctic

   Answer:

5. Rough surfaces promote boiling more than smooth surfaces. This is because:
   (a) the effective interface area is higher
   (b) there are more large bubble nucleation sites
   (c) the vapor/liquid surface tension is reduced

   Answer:

6. Solar swimming pool heaters are often unglazed. This is because:
   (a) The temperature difference between the water temperature and the ambient temperature is low (or even negative) and convective heat loss is correspondingly negligible.
   (b) Glazing reflects much of the incoming solar radiation
   (c) Glass is dangerous around a pool area

   Answer:

7. Fins in most naturally convecting heat sinks for electronic devices are spaced about 7 mm apart, while fin spacing in heat sinks designed for forced convection varies greatly. This is because:
   (a) There is only one large manufacturer of extrusions used in naturally convecting fins
   (b) The optimum fin spacing is approximately 7 mm for natural convection at temperatures encountered in cooling of electronic devices
   (c) In forced convection optimum spacing is not critical, so manufacturers just use whatever fins are cheapest

   Answer:

8. In a process where heat is removed by nucleate boiling, it is generally important to make sure that the critical heat flux is not exceeded. This is because:
   (a) if critical flux is exceeded, the boiling process could become unstable and create excessive vibration on the system
   (b) Exceeding the critical flux may result in a reduction in the temperature, leading to reduced heat transfer
   (c) Exceeding the critical heat flux results in an almost instantaneous very large increase in temperature

   Answer:

9. A selective radiating surface is one which:
   (a) Has different emissivity and absorptivity depending on the temperature
   (b) Has different emissivity and absorptivity depending on the wavelength
   (c) Has an emissivity which is different from its absorptivity at a given wavelength

   Answer:

10. Many thermally radiating / absorbing surfaces are dimpled or grooved. This is because:
    (a) The surface resistance is reduced
    (b) The configuration resistance is reduced
    (c) There is no heat transfer benefit, this is just done to enhance material stiffness

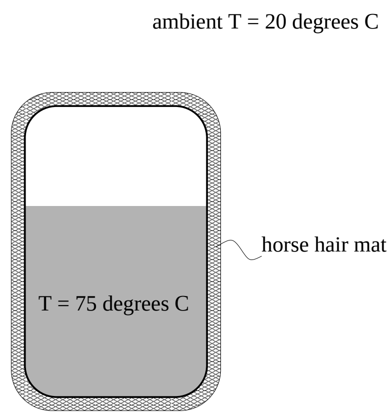
    Answer:

Part 2: Problems (25 points per question)

Attempt all problems in this section, clearly stating any assumptions and simplifications used in your solution.

Problem 1

A metal water heater tank contains 100 kg of water at 75°C in a room where the ambient temperature is 20°C. The surface area of the heater is 1.3 m^2. The manufacturer (which supplies heaters to a famous Swedish retailer) is planning to insulate the heater with matted horse hair (thermal conductivity 0.05 W/(m K)), a by-product from the nearby meat packing plant (also a supplier of the famous Swedish retailer). The technical requirement is that the water should not cool faster that 3°C per hour when the heater element is turned off. Calculate the required thickness of the hair mats. Assume that the water circulation by natural convection inside the tank ensures that the water temperature is, to a good approximation, uniform.



Hint: The problem can be made easier by neglecting the temperature drop across the metal tank wall and the air boundary layer around the insulation. Comment on the legitimacy of such an assumption.

Problem 2

A resistor is cylindrical in shape, 20 mm long, with a diameter of 1 mm. It is sheathed in a layer of electric insulation with a thermal conductivity 0.1 W/(m K), which can also be assumed cylindrical in shape. Assume that the resistor is dissipating 0.5W total of energy while operating, with 50% of the heat it generates transmitted through the copper leads, and the rest - dissipated from the sheathed surface. The surrounding air is at 300 K, and the surface convection coefficient between the air and the sheathing is h=16 W/(m^{2}K). Find the optimal insulation thickness for the best cooling effect. What is the resistor temperature?

Hint: only consider convection between the air and the cylindrical part of the resistor.

Problem 3

A conical hole is machined in a block of metal whose emissivity is 0.5. The hole is 2.5 cm in diameter at the surface and is 7.5 cm deep. If the metal block is held at 800 K, determine:

1. The view factor from the conical surface to large surroundings,
2. The radiation emitted by the hole to surroundings at 0 K,
3. The value of *apparent* emissivity of the hole, defined as the ratio of the actual power emitted by the hole to that power which would be emitted by a black surface having an area equal to that of the opening and a temperature equal to that of the inside surfaces.

Potentially useful material properties

T (K)	ρ (kg/m^3)	c_p (J/kg·K)	μ (kg/m·s)	ν (m^2/s)	k (W/m·K)	α (m^2/s)	Pr
				Air			
100	3.605	1039	0.711×10^{-5}	0.197×10^{-5}	0.00941	0.251×10^{-5}	0.784
150	2.368	1012	1.035	0.437	0.01406	0.587	0.745
200	1.769	1007	1.333	0.754	0.01836	1.031	0.731
250	1.412	1006	1.606	1.137	0.02241	1.578	0.721
260	1.358	1006	1.649	1.214	0.02329	1.705	0.712
270	1.308	1006	1.699	1.299	0.02400	1.824	0.712
280	1.261	1006	1.747	1.385	0.02473	1.879	0.711
290	1.217	1006	1.795	1.475	0.02544	2.078	0.710
300	1.177	1007	1.857	1.578	0.02623	2.213	0.713
310	1.139	1007	1.889	1.659	0.02684	2.340	0.709
320	1.103	1008	1.935	1.754	0.02753	2.476	0.708
330	1.070	1008	1.981	1.851	0.02821	2.616	0.708
340	1.038	1009	2.025	1.951	0.02888	2.821	0.707
350	1.008	1009	2.090	2.073	0.02984	2.931	0.707
400	0.8821	1014	2.310	2.619	0.03328	3.721	0.704
450	0.7840	1021	2.517	3.210	0.03656	4.567	0.703
500	0.7056	1030	2.713	3.845	0.03971	5.464	0.704
550	0.6414	1040	2.902	4.524	0.04277	6.412	0.706
600	0.5880	1051	3.082	5.242	0.04573	7.400	0.708
650	0.5427	1063	3.257	6.001	0.04863	8.430	0.712
700	0.5040	1075	3.425	6.796	0.05146	9.498	0.715
750	0.4704	1087	3.588	7.623	0.05425	10.61	0.719
800	0.4410	1099	3.747	8.497	0.05699	11.76	0.723
850	0.4150	1110	3.901	9.400	0.05969	12.96	0.725
900	0.3920	1121	4.052	10.34	0.06237	14.19	0.728
950	0.3716	1131	4.199	11.30	0.06501	15.47	0.731
1000	0.3528	1142	4.343	12.31	0.06763	16.79	0.733
1100	0.3207	1159	4.622	14.41	0.07281	19.59	0.736
1200	0.2940	1175	4.891	16.64	0.07792	22.56	0.738
1300	0.2714	1189	5.151	18.98	0.08297	25.71	0.738
1400	0.2520	1201	5.403	21.44	0.08798	29.05	0.738
1500	0.2352	1211	5.648	23.99	0.09296	32.64	0.735

Material properties ctd.

Temperature K	°C	ρ (kg/m^3)	c_p (J/kg·K)	k (W/m·K)	α (m^2/s)	ν (m^2/s)	Pr	β (K^{-1})
				Water				
273.16	0.01	999.8	4220	0.5610	1.330×10^{-7}	17.91×10^{-7}	13.47	-6.80×10^{-5}
275	2	999.9	4214	0.5645	1.340	16.82	12.55	-3.55×10^{-5}
280	7	999.9	4201	0.5740	1.366	14.34	10.63	4.36×10^{-5}
285	12	999.5	4193	0.5835	1.392	12.40	8.91	0.000112
290	17	998.8	4187	0.5927	1.417	10.85	7.66	0.000172
295	22	997.8	4183	0.6017	1.442	9.600	6.66	0.000226
300	27	996.5	4181	0.6103	1.465	8.568	5.85	0.000275
305	32	995.0	4180	0.6184	1.487	7.708	5.18	0.000319
310	37	993.3	4179	0.6260	1.508	6.982	4.63	0.000361
320	47	989.3	4181	0.6396	1.546	5.832	3.77	0.000436
340	67	979.5	4189	0.6605	1.610	4.308	2.68	0.000565
360	87	967.4	4202	0.6737	1.657	3.371	2.03	0.000679
373.15	100.0	958.3	4216	0.6791	1.681	2.940	1.75	0.000751
400	127	937.5	4256	0.6836	1.713	2.332	1.36	0.000895
420	147	919.9	4299	0.6825	1.726	2.030	1.18	0.001008
440	167	900.5	4357	0.6780	1.728	1.808	1.05	0.001132
460	187	879.5	4433	0.6702	1.719	1.641	0.955	0.001273
480	207	856.5	4533	0.6590	1.697	1.514	0.892	0.001440
500	227	831.3	4664	0.6439	1.660	1.416	0.853	0.001645
520	247	803.6	4838	0.6246	1.607	1.339	0.833	0.001909
540	267	772.8	5077	0.6001	1.530	1.278	0.835	0.002266
560	287	738.0	5423	0.5701	1.425	1.231	0.864	0.002783
580	307	697.6	5969	0.5346	1.284	1.195	0.931	0.003607
600	327	649.4	6953	0.4953	1.097	1.166	1.06	0.005141
620	347	586.9	9354	0.4541	0.8272	1.146	1.39	0.009092
640	367	481.5	25,940	0.4149	0.3322	1.148	3.46	0.03971
642	369	463.7	34,930	0.4180	0.2581	1.151	4.46	0.05679
644	371	440.7	58,910	0.4357	0.1678	1.156	6.89	0.1030
646	373	403.0	204,600	0.5280	0.06404	1.192	18.6	0.3952
647.0	374	357.3	3,905,000	1.323	0.00948	1.313	138.	7.735