University of New Mexico
Mechanical engineering
Fall 2017 Ph.D. qualifying examination

Heat Transfer

Notes

- Time allowed: 150 minutes.
- Closed book / Closed Notes (one 8.5 × 11.00 in. sheet of formulas is allowed).
- Calculators are allowed.
- Laptops, cell phones, and similar electronic devices cannot be used.

Part 1: General knowledge (25 points)
Circle the correct answer

1. A black body...
   (a) absorbs all radiation that is incident on it
   (b) emits the minimum energy possible for a given temperature and wavelength of radiation
   (c) emits radiation with a preferential direction
2. What is a necessary condition for a thermal-circuit analogy to be applicable?
   (a) a body is being quenched by immersing it in liquid
   (b) heat transfer is dominated by conduction
   (c) heat transfer can be approximated as one-dimensional
3. In a lumped system...
   (a) temperature is a function of position only
   (b) Biot number is much greater than unity
   (c) Biot number is much smaller than unity
4. The Fourier number is most relevant for problems involving...
   (a) black-body radiation
   (b) transient conduction
   (c) turbulent convection
5. For a gray surface...
   (a) emissivity and absorptivity are independent of direction
   (b) emissivity and absorptivity are independent of wavelength
   (c) the sum of emissivity and absorptivity equals unity
6. If a surface emits 100 W at a temperature 300 K, how much energy will it emit at a temperature 600 K?
   (a) 1600 W
   (b) 400 W
   (c) 200 W

7. In a heat exchanger, is it possible for the exit temperature of the cold fluid to be greater than the exit temperature of the hot fluid when both fluids are single phase fluids?

   (a) yes

   (b) no

   (c) only in a counterflow heat exchanger

8. In hot air flowing inside a cool pipe...

   (a) the thermal boundary layer is likely much thinner than the velocity boundary layer

   (b) the thermal boundary layer is likely much thicker than the velocity boundary layer

   (c) the thickness of the thermal and the velocity boundary layers is on the same order

9. Thermal conductivity is defined as the heat flow per unit time...

   (a) when temperature gradient is unity

   (b) through a unit thickness of the wall

   (c) across unit area where temperature gradient is unity

10. Which one of the following forms of water have the highest value of thermal conductivity?

   (a) steam

   (b) boiling water

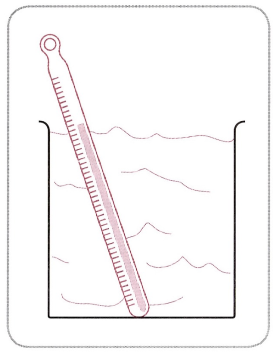
   (c) solid ice

Part 2: Problems (25 points per question)

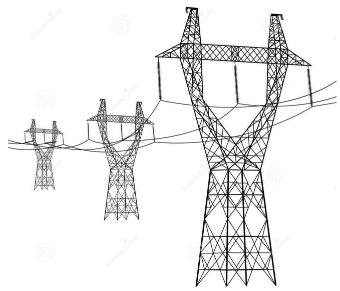
Attempt all problems in this section, clearly stating any assumptions and simplifications used in your solution

Problem 1

A mercury-in-glass thermometer 3 mm in diameter and 200 mm long, initially at 15°C is placed in water at uniform 75°C. Calculate the time required for the thermometer to indicate a temperature that is within 3°C of the actual water temperature. Assume that the convection coefficient h is 180 $W/m^2{\cdot}°C$ for the water/thermometer interface, and that the thermometer has the same properties as glass. State any required assumptions.



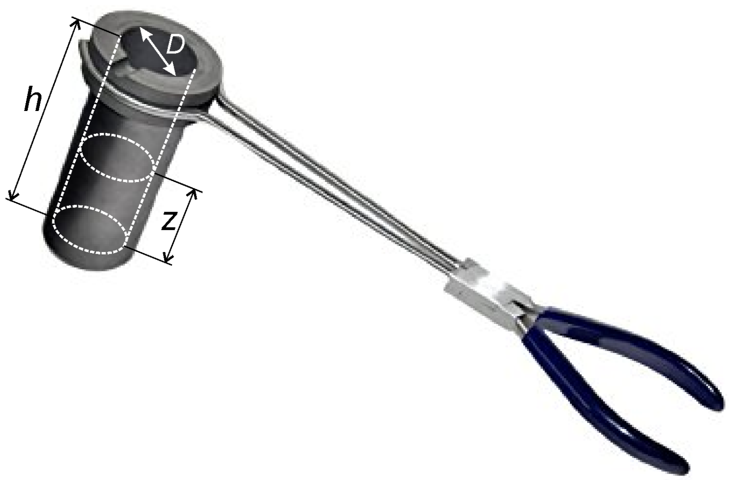
Problem 2



Predict the convective heat transfer coefficient for a power transmission line 6 cm in diameter, when air at 0°C and 10 m/s flows across the wire. If the resistance per unit length of the aluminum wire is $1.13\times10^{-5}\Omega/\mathrm{m}$, what is the maximum power that can be transmitted by the 100 kV line, if the maximum operating temperature of the wire is 40°C?

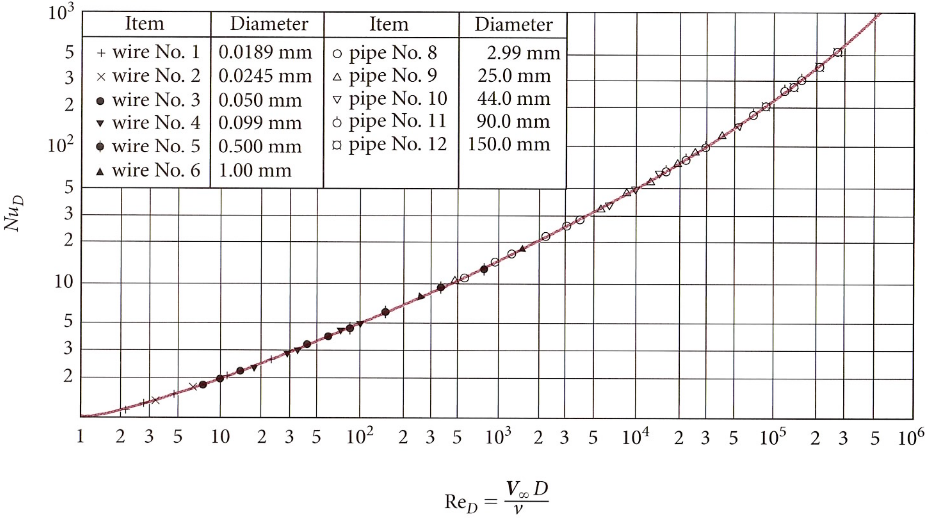
Note: resistive loss $P_\Omega = I^2 R$, *power through line* $P = VI$.

Problem 3



The interior cavity of a crucible is cylindrical in shape, with a diameter $D = 0.125$ m and a depth $h = 0.125$ m. Inside the crucible is molten metal with an average temperature $T = 600$ K. The depth of the liquid metal in the crucible is $z = 0.075$ m. Making the simplest assumptions about the properties of the surfaces and materials involved, estimate the rate of radiative heat loss from the surface of metal in the crucible.

Material	Temperature T (K)	Density ρ (kg/m^3)	Specific Heat c_p (kJ/kg · K)	Thermal Conductivity κ(W/m · K)	Isobaric Compressibility $\beta_p \times 10^6$ (K^{-1})
Glass	300	2,500	0.750	1.40	210
Glass Fiber	300	220	—	0.035	—
Glass Wool	300	40	0.70	0.038	—
Gypsum Board (Plaster)	300	817	1.084	0.107	—
Ice	273	920	2.04	2.20	—
Mineral Wool (Batts)	300	—	—	0.039	—
Paper	300	73	1.510	0.096	—
Peat	300	275	1.700	0.109	—
Polystyrene, Styrofoam	300	37	—	0.029	21
Polyurethane Foam, rigid	300	40	—	0.023	40.5
Rock Wool	300	160	—	0.040	—
Rubber					
Foam	300	70	—	0.032	—
Hard	300	1,190	2.01	0.160	180
Sand, dry	300	1,515	0.80	0.30	—
Sawdust	300	215	—	0.059	—
Saw Shavings	300	215	—	0.059	—
Snow					
Loose	273	110	—	0.05	—
Packed	273	500	—	0.19	—
Soil	300	2,050	1.840	0.52	—
Sulfur	300	1,920	0.736	0.270	126
Stone					
Granite	300	2,630	0.775	2.79	24
Limestone	300	2,320	0.810	2.15	18
Marble	300	2720	0.920	3.00	45
Sandstone	300	2150	0.745	2.90	30
Teflon	300	2200	1.00	0.35	—
Tissue, Human					
Fat	300	*	—	0.20	—
Muscle	300	*	—	0.41	—
Skin	300	*	—	0.37	—


Item
Diameter
Item
Diameter
+ wire No. 1
0.0189 mm
× wire No. 2
0.0245 mm
● wire No. 3
0.050 mm
▼ wire No. 4
0.099 mm
wire No. 5
0.500 mm
▲ wire No. 6
1.00 mm
○ pipe No. 8
2.99 mm
△ pipe No. 9
25.0 mm
▽ pipe No. 10
44.0 mm
pipe No. 11
90.0 mm
pipe No. 12
150.0 mm
Nu_D
10^3
10^2
10
1
2
3
5
10^4
10^5
10^6
$\mathrm{Re}_D = \frac{V_\infty D}{\nu}$

Material	Temperature T(K)	Density, ρ(kg/m^3)	Specific Heat, c_p (kJ/kg · K)	Thermal Conductivity κ(W/m · K)	Viscosity μ(g/m · s)	Prandtl Number	Isobaric Compressibility $\beta_p \times 10^3$ (K^{-1})
Air	250	1.4136	1.007	0.022	0.016	0.732	4.00
	300	1.178	1.007	0.026	0.0181	0.701	3.33
	350	1.0097	1.010	0.030	0.0204	0.687	2.857
	400	0.8835	1.014	0.034	0.023	0.686	2.50
Ammonia	200	1.033	2.000	0.0132	0.00689	1.044	—
	300	0.689	2.096	0.0250	0.01020	0.855	—
	400	0.540	2.290	0.0374	0.01390	0.851	—
Carbon Dioxide	300	1.81	0.844	0.017	0.0148	0.735	—
Carbon Monoxide	300	1.16	1.040	0.025	0.0182	0.757	—
Ethanol	300	1.864	1.430	0.0220	0.0090	0.585	—
	400	1.398	1.765	0.0264	0.0118	0.789	—
	500	1.120	2.052	0.0381	0.0141	0.759	—
Helium	200	0.2462	5.193	0.1151	0.0150	0.677	—
	300	0.1625	5.193	0.152	0.0199	0.680	—
	400	0.1219	5.193	0.187	0.0243	0.675	—
	600	0.0836	5.193	0.220	0.0283	0.668	—
	1000	0.04879	5.193	0.354	0.0446	0.654	—
Hydrogen	300	0.0817	14.302	0.190	0.0090	0.677	—
Methane	300	0.655	2.227	0.0341	0.0134	0.875	—
Methanol	300	1.296	1.378	0.0230	0.0083	0.497	—
	400	0.972	1.619	0.0261	0.0131	0.813	—
	500	0.778	1.864	0.0375	0.0165	0.820	—
Nitrogen	300	1.15	1.040	0.026	0.0176	0.704	—
Oxygen	300	1.31	0.911	0.027	0.0200	0.675	—
Propane	300	—	1.696	0.0182	0.0083	0.773	—
Propanol	300	2.40	1.917	0.0254	0.0106	0.800	—
R-12	243	6.289	0.572	0.0070	0.0105	0.858	—
	283 at 0.423 MPa	24.19	0.658	0.0091	0.0125	0.904	—
	333 at 1.523 MPa	89.04	0.880	0.0125	0.0160	1.126	—
R-22	233	4.705	0.606	0.0069	—	—	—
	273 at 0.5 MPa	21.26	0.744	0.0095	0.0118	0.924	—
	323 at 2.00 MPa	86.13	1.129	0.0124	0.0127	1.156	—