GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Quarter 1995

HEAT TRANSFER

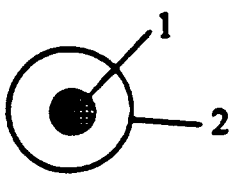
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

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

HEAT TRANSFER
Ph.D. QUALIFYING EXAMS
Spring 1995

The two spheres shown interchange radiant energy in the space between surfaces 1 and 2.



$D_1 = 1m$, $D_2 = 2m$

$T_1 = 500$ k, $T_2 = 800$ k

Determine the view factors F_{12}, F_{21}, F_{11}, and F_{22}.

If the surfaces are black, determine the direction (from or to the surface) and magnitude of total heat transfer at surface 1 and surface 2. If both surfaces are gray with $\varepsilon_1 = 0.8$ and $\varepsilon_2 = 0.9$ determine the radiosity for surface 1 and for surface 2. Determine the magnitude and direction of total heat transfer for surface 1 and surface 2.

Derive the enclosure equations to develop the expressions you use to find radiosities and heat transfers.

SCHOOL OF MECHANICAL ENGINEERING
Heat Transfer
Qualifying Exam
Spring 1995

Liquid refrigerant-12 at a temperature of $T_\infty = 7°C$ interacts with the surface of a flat plate whose temperature is $T_s = 47°C$. The free stream velocity of the fluid is 100 m/h. At a characteristic length of L = 1 m, the temperature distribution is

$$(T_s - T)/(T_s - T_\infty) = 16.242y - 49.460y^2$$

where T is in °C and y in meters. Using the average fluid temperature for evaluation of properties, calculate at the characteristic length:

a. The Reynolds number.
b. The temperature gradient at the interface (y = 0) and include appropriate units.
c. The temperature at y = 0.05 m.
d. The rate of heat transferred to the fluid.

Heat is generated at a constant rate of $g'''(W/m^3)$ in a thin circular rod of length L and diameter D by the passage of electrical current. The two ends at x = 0 and x = L are kept at constant temperatures T(x = 0) = T_0 and T(x = L) = 0, respectively, while heat is dissipated from the lateral surfaces by convection into a medium at $T_\infty = 0$ with a heat transfer coefficient, h.

(a). Derive the one-dimensional steady state energy equation for the determination of the temperature distribution, T(x) in the rod.

(b). Cast the result from Part (a) above in dimensionless form and solve the derived differential equation to provide an equation for the temperature distribution in the rod.

(c). Sketch the resulting dimensionless temperature profile. Show the general behavior ---- do not even attempt to compute or plot numerical data---since you have not been given specific property or geometric data. Discuss how the magnitude of axial conduction and surface convection varies along the surface. from the x=0 end to the x=L end.

Table A.5 Thermophysical properties of saturated fluids[a]

Saturated liquids

T (K)	ρ (kg/m³)	c_p (kJ/kg · K)	μ · 10² (N · s/m²)	ν · 10⁶ (m²/s)	k · 10³ (W/m · K)	α · 10⁷ (m²/s)	Pr	β · 10³ (K⁻¹)
Engine Oil (unused)								
273	899.1	1.796	385	4,280	147	0.910	47,000	0.70
280	895.3	1.827	217	2,430	144	0.880	27,500	0.70
290	890.0	1.868	99.9	1,120	145	0.872	12,900	0.70
300	884.1	1.909	48.6	550	145	0.859	6,400	0.70
310	877.9	1.951	25.3	288	145	0.847	3,400	0.70
320	871.8	1.993	14.1	161	143	0.823	1,965	0.70
330	865.8	2.035	8.36	96.6	141	0.800	1,205	0.70
340	859.9	2.076	5.31	61.7	139	0.779	793	0.70
350	853.9	2.118	3.56	41.7	138	0.763	546	0.70
360	847.8	2.161	2.52	29.7	138	0.753	395	0.70
370	841.8	2.206	1.86	22.0	137	0.738	300	0.70
380	836.0	2.250	1.41	16.9	136	0.723	233	0.70
390	830.6	2.294	1.10	13.3	135	0.709	187	0.70
400	825.1	2.337	0.874	10.6	134	0.695	152	0.70
410	818.9	2.381	0.698	8.52	133	0.682	125	0.70
420	812.1	2.427	0.564	6.94	133	0.675	103	0.70
430	806.5	2.471	0.470	5.83	132	0.662	88	0.70
Ethylene Glycol [$C_2H_4(OH)_2$]								
273	1,130.8	2.294	6.51	57.6	242	0.933	617	0.65
280	1,125.8	2.323	4.20	37.3	244	0.933	400	0.65
290	1,118.8	2.368	2.47	22.1	248	0.936	236	0.65
300	1,114.4	2.415	1.57	14.1	252	0.939	151	0.65
310	1,103.7	2.460	1.07	9.65	255	0.939	103	0.65
320	1,096.2	2.505	0.757	6.91	258	0.940	73.5	0.65
330	1,089.5	2.549	0.561	5.15	260	0.936	55.0	0.65
340	1,083.8	2.592	0.431	3.98	261	0.929	42.8	0.65
350	1,079.0	2.637	0.342	3.17	261	0.917	34.6	0.65
360	1,074.0	2.682	0.278	2.59	261	0.906	28.6	0.65
370	1,066.7	2.728	0.228	2.14	262	0.900	23.7	0.65
373	1,058.5	2.742	0.215	2.03	263	0.906	22.4	0.65
Glycerin [$C_3H_5(OH)_3$]								
273	1,276.0	2.261	1,060	8,310	282	0.977	85,000	0.47
280	1,271.9	2.298	534	4,200	284	0.972	43,200	0.47
290	1,265.8	2.367	185	1,460	286	0.955	15,300	0.48
300	1,259.9	2.427	79.9	634	286	0.935	6,780	0.48
310	1,253.9	2.490	35.2	281	286	0.916	3,060	0.49
320	1,247.2	2.564	21.0	168	287	0.897	1,870	0.50
Freon (refrigerant-12) (CCl_2F_2)								
230	1,528.4	0.8816	0.0457	0.299	68	0.505	5.9	1.85
240	1,498.0	0.8923	0.0385	0.257	69	0.516	5.0	1.90
250	1,469.5	0.9037	0.0354	0.241	70	0.527	4.6	2.00
260	1,439.0	0.9163	0.0322	0.224	73	0.554	4.0	21.0

Table A.5 Continued

Saturated liquids Continued

T (K)	ρ (kg/m³)	c_p (kJ/kg · K)	μ · 10² (N · s/m²)	ν · 10⁶ (m²/s)	k · 10³ (W/m · K)	α · 10⁷ (m²/s)	Pr	β · 10³ (K⁻¹)
Freon (refrigerant-12) (CCl_2F_2) Continued								
270	1,407.2	0.9301	0.0304	0.216	73	0.558	3.9	2.25
280	1,374.4	0.9450	0.0283	0.206	73	0.562	3.7	2.35
290	1,340.5	0.9609	0.0265	0.198	73	0.567	3.5	2.55
300	1,305.8	0.9781	0.0254	0.195	72	0.564	3.5	2.75
310	1,268.9	0.9963	0.0244	0.192	69	0.546	3.4	3.05
320	1,228.6	1.0155	0.0233	0.190	68	0.545	3.5	3.5
Mercury (Hg)								
273	13,595	0.1404	0.1688	0.1240	8,180	42.85	0.0290	0.181
300	13,529	0.1393	0.1523	0.1125	8,540	45.30	0.0248	0.181
350	13,407	0.1377	0.1309	0.0976	9,180	49.75	0.0196	0.181
400	13,287	0.1365	0.1171	0.0882	9,800	54.05	0.0163	0.181
450	13,167	0.1357	0.1075	0.0816	10,400	58.10	0.0140	0.181
500	13,048	0.1353	0.1007	0.0771	10,950	61.90	0.0125	0.182
550	12,929	0.1352	0.0953	0.0737	11,450	65.55	0.0112	0.184
600	12,809	0.1355	0.0911	0.0711	11,950	68.80	0.0103	0.187

Saturated liquid–vapor, 1 atm[b]

FLUID	T_{sat} (K)	h_{fg} (kJ/kg)	ρ_f (kg/m³)	ρ_g (kg/m³)	σ · 10³ (N/m)
Ethanol	351	846	757	1.44	17.7
Ethylene Glycol	470	812	1,111[c]	—	32.7
Glycerin	563	974	1,260[c]	—	63.0[c]
Mercury	630	301	12,740	3.90	417
Refrigerant R-12	243	165	1,488	6.32	15.8
Refrigerant R-113	321	147	1,511	7.38	15.9

[a] Adapted from references 15 and 16.
[b] Adapted from references 8, 17, and 18.
[c] Property value corresponding to 300 K.

GRAPHS OF HYPERBOLIC FUNCTIONS

8.49 $y = \sinh x$

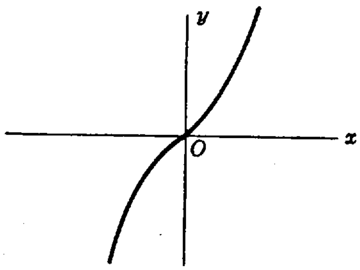


Fig. 8-1

8.50 $y = \cosh x$

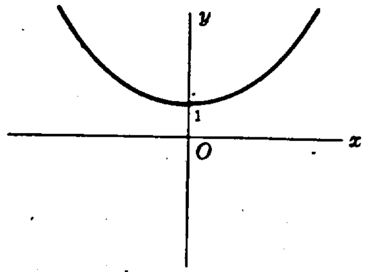


Fig. 8-2

8.51 $y = \tanh x$

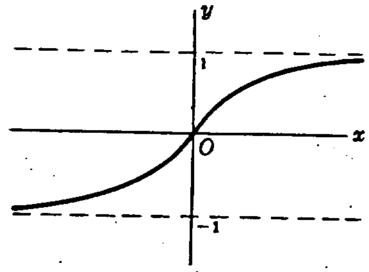


Fig. 8-3

8.52 $y = \coth x$

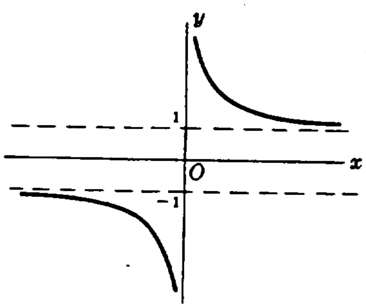


Fig. 8-4

8.53 $y = \operatorname{sech} x$

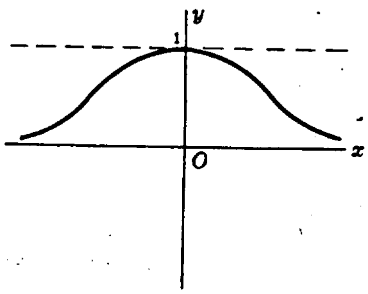


Fig. 8-5

8.54 $y = \operatorname{csch} x$

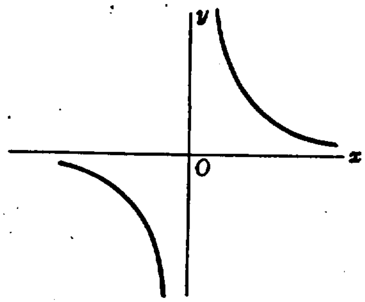


Fig. 8-6

DEFINITION OF HYPERBOLIC FUNCTIONS

8.1 *Hyperbolic sine of x* $= \sinh x = \dfrac{e^x - e^{-x}}{2}$

8.2 *Hyperbolic cosine of x* $= \cosh x = \dfrac{e^x + e^{-x}}{2}$

8.3 *Hyperbolic tangent of x* $= \tanh x = \dfrac{e^x - e^{-x}}{e^x + e^{-x}}$

8.4 *Hyperbolic cotangent of x* $= \coth x = \dfrac{e^x + e^{-x}}{e^x - e^{-x}}$

8.5 *Hyperbolic secant of x* $= \operatorname{sech} x = \dfrac{2}{e^x + e^{-x}}$

8.6 *Hyperbolic cosecant of x* $= \operatorname{csch} x = \dfrac{2}{e^x - e^{-x}}$

RELATIONSHIPS AMONG HYPERBOLIC FUNCTIONS

8.7 $\tanh x = \dfrac{\sinh x}{\cosh x}$

8.8 $\coth x = \dfrac{1}{\tanh x} = \dfrac{\cosh x}{\sinh x}$

8.9 $\operatorname{sech} x = \dfrac{1}{\cosh x}$

8.10 $\operatorname{csch} x = \dfrac{1}{\sinh x}$

8.11 $\cosh^2 x - \sinh^2 x = 1$

8.12 $\operatorname{sech}^2 x + \tanh^2 x = 1$

8.13 $\coth^2 x - \operatorname{csch}^2 x = 1$

DERIVATIVES OF HYPERBOLIC AND INVERSE HYPERBOLIC FUNCTIONS

13.31 $\dfrac{d}{dx}\sinh u = \cosh u \dfrac{du}{dx}$

13.32 $\dfrac{d}{dx}\cosh u = \sinh u \dfrac{du}{dx}$

13.33 $\dfrac{d}{dx}\tanh u = \operatorname{sech}^2 u \dfrac{du}{dx}$

13.34 $\dfrac{d}{dx}\coth u = -\operatorname{csch}^2 u \dfrac{du}{dx}$

13.35 $\dfrac{d}{dx}\operatorname{sech} u = -\operatorname{sech} u \tanh u \dfrac{du}{dx}$

13.36 $\dfrac{d}{dx}\operatorname{csch} u = -\operatorname{csch} u \coth u \dfrac{du}{dx}$