AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING

AEROSPACE

AERO 4970/7970 **Rocket Propulsion I** **SET III**

Heat Transfer Analysis of Rocket Systems

1. Compute the total or stagnation temperature that would occur ideally at the nose of a vehicle flying at an attitude of 25 km and a Mach number of 6. Assume isentropic conditions, an ambient air temperature of 203K, k=1.4, and a molecular mass of 29 kg/kmol.
   Answer: 1,665 K.

2. How much total heat per second can be absorbed in a thrust chamber with an inside wall surface area of 0.2 m^2 if the coolant is aniline and the coolant does not exceed 145 ^oC in the jacket? Assume the average specific heat of aniline to equal 0.45 kcal/kg-K, an inlet temperature of 26 ^oC, and a coolant flow of 2 kg/s. What is the average heat transfer rate per second per unit area?

3. During a static test, a certain thrust chamber is cooled by water. The following data are given:

Average water temperature	100 ^oF
Thermal conductivity of water	1.07×10^{-4} Btu/sec-ft-^oF
Gas temperature	4500 ^oF
Viscosity of water	2.5×10^{-5} lb-sec/ft^2
Specific heat of water	1 Btu/lb-^oF
Cooling passage dimensions	$\frac{1}{4}\times\frac{1}{2}$ in
Water flow through passage	0.585 lb/sec
Thickness of inner wall	$\frac{1}{8}$ in
Heat absorbed	1.3 Btu/in^2-sec
Thermal conductivity of wall material	26 Btu/hr-ft-^oF

   Determine: (a) the film coefficient of the coolant; (b) the wall temperature on the coolant side; and (c) the wall temperature on the gas side.

4. In Problem 3, determine the water flow required to decrease the wall temperature on the gas side by 100 ^oF. What is the percentage increase in coolant velocity? Assume that the various properties of the water and the average water temperature do not change.

5. Determine the absolute and relative reductions in wall temperatures and heat transfer caused by applying insulation in a liquid-cooled rocket chamber with the following data:

Tube wall thickness	0.381 mm
Gas temperature	2760 K
Gas-side wall temperature	1260 K
Heat transfer rate	15 MW/m^2
Liquid film coefficient	23 kW/m^2
Wall material (see table below)	Stainless steel AISI type 302

An 0.2 mm thick layer of insulating paint is applied on the gas side; the paint consists mostly of magnesia particles. The conductivity of this magnesia is 2.59 W/m-K.

	Copper, Com. Pure	Aluminum Alloy, 24S-T	Low Carbon Steel, SAE 1020	Alloy Steel, SAE X4130	Stainless Steel, AISI Type 302	Nickel Alloy, Inconel
Ultimate tensile strength (psi)	75°F 33,000	75°F 68,000 212 62,000 500 26,000 600 15,000 700 7500	85°F 62,400 900 45,500 1000 36,500 1200 20,000 1300 13,500 1400 9025	75°F 98,300 600 87,000 800 84,000 1000 65,000	75°F 93,000 200 83,000 600 76,200 1000 65,600 1400 31,800 1600 15,700 2000 4700 2300 2300	75°F 85,000 200 81,000 600 79,000 1000 79,000 1400 47,000 1600 23,000 1800 15,000 2000 11,000
Yield strength (psi)	Annealed 75°F 10,000	Short time test 75°F 45,000 400 35,000 500 23,000 600 13,000 700 6500	85°F 42,000 900 23,500 1000 20,100 1300 7375 1400 3750	Normalized 75°F 74,000 400 73,600 800 66,000 900 59,300 1000 53,400	Annealed 75°F 37,000 200 29,700 600 22,000 1000 17,100 1400 14,900	Short time test 75°F 36,000 200 32,000 600 27,000 1000 22,000 1400 19,000
Modulus of elasticity (psi × 10^6)	Annealed 75°F 16.0	0.02% offset Short time test 75°F 10.3 212 10.0 300 9.78 400 9.27 500 8.24	70°F 29.5 400 24.5 600 21.5 800 18.5 1000 15.5 1200 12.5	Normalized 70°F 29.5 400 24.5 600 21.5 800 18.5 1000 15.5 1200 12.5	Annealed 85°F 27.5 900 23.4 1000 22.2 1200 20.7 1400 18.3 1500 13.3	0.2% offset Short time test 75°F 31.0 500 28.7 1000 25.0 1350 21.0 1500 18.5
Thermal conductivity (Btu/hr ft² °F/in.)	32°F 2648.6 392 2579.3 752 2516.9 1112 2392.1	64°F 1567.0	32°F 360.5 392 339.7 752 298.1 1472 179.6 1832 187.2 2012 194.1 2192 208.0	32°F 298.1 392 291.2 752 270.4 1112 235.7 1472 180.3 1832 194.1 2192 208.0	32°F 110 392 119 752 136 1112 159 1472 180 1832 194 2192 206	86°F 124.8 392 131.7 1472 194.1 2192 249.6
Coefficient of thermal expansion (in./in. °F × 10^{-6})	32°F 8.83 572 10.91 752 11.86 932 12.94 1112 14.15 1472 16.97	68–212°F 12.9 68–392 13.3 68–572 13.7	68–212°F 6.5 68–392 6.7 68–572 7.1 68–932 7.7 68–1112 8.0 68–1292 8.2	32–212°F 7.04 32–572 7.48 32–932 7.88 32–1292 8.24 32–1652 7.23 32–1832 7.70 32–2012 8.04	32–212°F 8.23 32–572 9.50 32–932 10.02 32–1292 10.43 32–1652 10.67 32–1832 10.75	50°F 5.6 200 6.8 400 8.0 600 8.7 800 9.3 1000 10.1 1400 10.2
Specific heat (Btu/°F lb)	75°F 0.0918 392 0.096 752 0.100 1472 0.109 1832 0.114	64–212°F 0.212	68°F 0.115 572 0.133 932 0.150 1292 0.152 1652 0.154 2012 0.156 2372 0.166	212°F 0.114 572 0.130 932 0.157 1292 0.197 1472 0.211 1832 0.145 2282 0.154	212°F 0.122 572 0.131 932 0.142 1292 0.149 1652 0.156 2012 0.158 2282 0.162	78–212°F 0.109
Melting point	1981.4°F	Approx. 2700°F	Approx. 2780°F	Approx. 2700°F	2550°F	2540°F