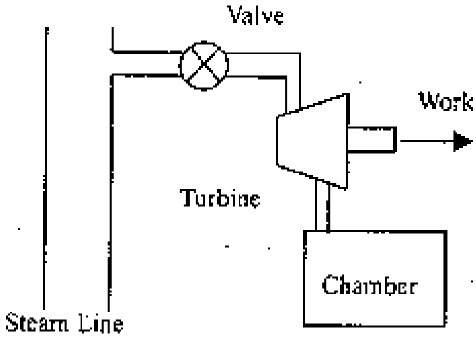
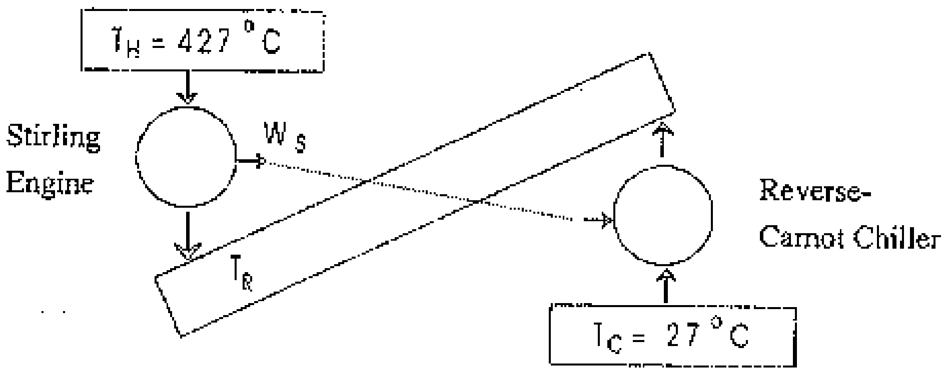
1. An adiabatic rigid chamber is connected to a steam line that provides steam at a constant state of T = 700 °C, P = 2000 kPa. An adiabatic turbine is in the adiabatic connecting line between the steam supply line and the chamber as shown. Initially, the chamber (V = 10 m^3) contains 8 kg of steam at 100 kPa. At time t = 0, the valve from the steam supply line is opened, and steam flows through the turbine and into the chamber. The valve is closed when the pressure in the chamber just reaches 2000 kPa, and at that instant, the temperature in the chamber is measured to be 600 °C. How much entropy S_{gen} (kJ/K) is generated in this process from the time the valve is opened until it is closed? (15%)



2. An ideal air-standard Stirling engine receives energy at a rate of 1 kW from a source at 427 °C, and has a thermodynamic efficiency of 0.50. The work output from the Stirling engine is used to drive a reverse-Carnot cycle chiller. The chiller absorbs energy from water at 27 °C, and rejects energy to the same reservoir for heat rejection used by the Stirling engine.

(a) What is the COP of the chiller? (10%)

(b) What is the rate of cooling (that is, the rate of heat transfer from the reservoir at 27 °C) provided by the chiller? (10%)



3. Derive a relation for the volume expansivity β and the isothermal compressibility α (a) for an ideal gas and (b) for a gas whose equation of state is $P(v - a) = RT$. (c) For the gas with equation of state $P(v - a) = RT$, is it possible to cool this gas by throttling assuming $a > 0$? (15%)

4. A small star has a radius of 100,000 km. Suppose that the star is originally at a uniform temperature of 1,000,000 K before it "dies," *i.e.*, before nuclear fusion stops supplying heat. If it is assumed that the star has a constant heat capacity of ρc_p = 1 kJ/m^{3}K, and that it remains isothermal during cool-down, estimate the time required until the star has cooled to 10,000 K. Note: A body of such proportions radiates like a blackbody. The Stefan-Boltzmann constant is 5.67 x 10^{-8} W/m^{2}K^4. (15%)

5. What are the definitions and their physical meanings of the following terms? (12%)

(a) thermal conductivity (b) Biot number (Bi)

(c) fin efficiency (d) Reynolds number (Re_L)

(e) Nusselt number (Nu_D) (f) Prandtl number (Pr)

6. Sketch the variation of the velocity and thermal boundary layer thickness qualitatively with distance froi the leading edge of a flat plate for the laminar flow of (a) air, (b) water, (c) engine oil, and (d) mercur Plot one figure for each fluid, and totally four figures. Assume a mean temperature of 300K for all fluid (8%)

7. A thin-walled copper tube of outside radius 10 mm is used to transport a low-temperature refrigerant an is at a temperature of 4 °C. The ambient air is at 25 °C and with convection coefficient h = 10 W/m²l around the tube. Foamed rubber with conductivity k = 0.032 W/mK is used as tube insulation to prever heat loss from air to the refrigerant.

(a) Plot the variation of conduction (R_{cond}), convection (R_{conv}) and total (R_{total}) thermal resistance vs. thicknes of the insulator (t). (5%)

(b) Is there a best or a worst thickness associated with application of insulation to the tube? Verify you answer quantitatively. (10%)

Tables for Problem 1

Saturated water—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/(kg · K)		
Press., P MPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.100	99.63	0.001043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
0.125	105.99	0.001048	1.3749	444.19	2069.3	2513.5	444.32	2241.0	2685.4	1.3740	5.9104	7.2844
0.150	111.37	0.001053	1.1593	466.94	2052.7	2519.7	467.11	2226.5	2693.6	1.4336	5.7897	7.2233
0.175	116.06	0.001057	1.0036	486.80	2038.1	2524.9	486.99	2213.6	2700.6	1.4849	5.6868	7.1717
0.200	120.23	0.001061	0.8857	504.49	2025.0	2529.5	504.70	2201.9	2706.7	1.5301	5.5970	7.1271
0.225	124.00	0.001064	0.7933	520.47	2013.1	2533.6	520.72	2191.3	2712.1	1.5706	5.5173	7.0878
0.250	127.44	0.001067	0.7187	535.10	2002.1	2537.2	535.37	2181.5	2716.9	1.6072	5.4455	7.0527
0.275	130.60	0.001070	0.6573	548.59	1991.9	2540.5	548.89	2172.4	2721.3	1.6408	5.3801	7.0209
0.300	133.55	0.001073	0.6058	561.15	1982.4	2543.6	561.47	2163.8	2725.3	1.6718	5.3201	6.9919

Superheated water (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/(kg · K)	v m³/kg	u kJ/kg	h kJ/kg	s kJ/(kg · K)	v m³/kg	u kJ/kg	h kJ/kg	s kJ/(kg · K)
	P = 1.60 MPa (201.41°C)				P = 1.80 MPa (207.15°C)				P = 2.00 MPa (212.42°C)			
Sat.	0.12380	2596.0	2794.0	6.4218	0.11042	2598.4	2797.1	6.3794	0.09963	2600.3	2799.5	6.3409
225	0.13287	2644.7	2857.3	6.5518	0.11673	2636.6	2846.7	6.4808	0.10377	2628.3	2835.8	6.4147
250	0.14184	2692.3	2919.2	6.6732	0.12497	2686.0	2911.0	6.6066	0.11144	2679.6	2902.5	6.5453
300	0.15862	2781.1	3034.8	6.8844	0.14021	2776.9	3029.2	6.8226	0.12547	2772.6	3023.5	6.7664
350	0.17456	2866.1	3145.4	7.0694	0.15457	2863.0	3141.2	7.0100	0.13857	2859.8	3137.0	6.9563
400	0.19005	2950.1	3254.2	7.2374	0.16847	2947.7	3250.9	7.1794	0.15120	2945.2	3247.6	7.1271
500	0.2203	3119.5	3472.0	7.5390	0.19550	3117.9	3469.8	7.4825	0.17568	3116.2	3467.6	7.4317
600	0.2500	3293.3	3693.2	7.8080	0.2220	3292.1	3691.7	7.7523	0.19960	3290.9	3690.1	7.7024
700	0.2794	3472.7	3919.7	8.0535	0.2482	3471.8	3918.5	7.9983	0.2232	3470.9	3917.4	7.9487
800	0.3086	3658.3	4152.1	8.2808	0.2742	3657.6	4151.2	8.2258	0.2467	3657.0	4150.3	8.1765
900	0.3377	3850.5	4390.8	8.4935	0.3001	3849.9	4390.1	8.4386	0.2700	[illegible]	[illegible]	[illegible]