1. (5%) Please use P-v diagram or T-s diagram to explain why a supercritical power cycle will have a better thermal efficiency whereas compared with the traditional power cycle.
2. (5%) What is the physical meaning of the number of transfer NTU? What does small NTU values tell about a heat transfer system?
3. (20%) The Carnot cycle provides a specific example of a reversible power cycle operating between two thermal reservoirs (with temperatures in the hot and cold reservoirs being T_h and T_c, respectively). In the cycle, the system undergoes a series of four internally reversible processes: two adiabatic processes alternated with two isothermal processes. Consider a piston-cylinder assembly, whose walls are non-conducting. N moles of a monatomic ideal gas are to be employed as the working fluid. The ideal gas is initially in contact with the hot reservoir, and in the first stage of the cycle it is expanded from volume V_1 to V_2. (a) First plot the processes (1-2-3-4-1) on the P-V diagram and T-S diagram, indicated with associated interpretations and the parameters of T and V as given herein. (b) Calculate the work and heat transfers in each of the four steps of the cycle, in terms of T_h, T_c, V_1, V_2, and N. (c) Directly corroborate that the efficiency of the cycle is the Carnot efficiency, which is a function of T_h and T_c.

   [Hint]: The ideal gas has entropy and energy as functions of T, V, and N:

   $$S = Ns_0 + NRln\left(\frac{T^{3/2}VN_0}{T_0^{3/2}V_0N}\right) \qquad U = \frac{3}{2}NRT,$$

   where the subscript '0' designates a reference state.
4. (10%) In the immediate vicinity of the state (T_0, v_0), the volume of a particular system of 1 mole is observed to vary according to the relationship

   $$v = v_0 + a(T - T_0) + b(P - P_0)$$

   Calculate the transfer of heat dQ to the system if the molar volume is changed by a small increment $dv = v - v_0$ at constant temperature, T_0.
5. (15%) To defog the rear window of an automobile, a very thin transparent heating element is attached to the inner surface of the window. A uniform heat flux of 1200 W/m^2 is provided to the heating element for defogging a rear window with thickness of 5 mm. The interior temperature of the automobile is 23 °C and the convection heat transfer coefficient is 12 W/m^2•K. The outside ambient temperature is – 10 °C and the convection heat transfer coefficient is 100 W/m^2•K. If the thermal conductivity of the window is 1.0 W/m•K, determine the inner surface temperature of the window.

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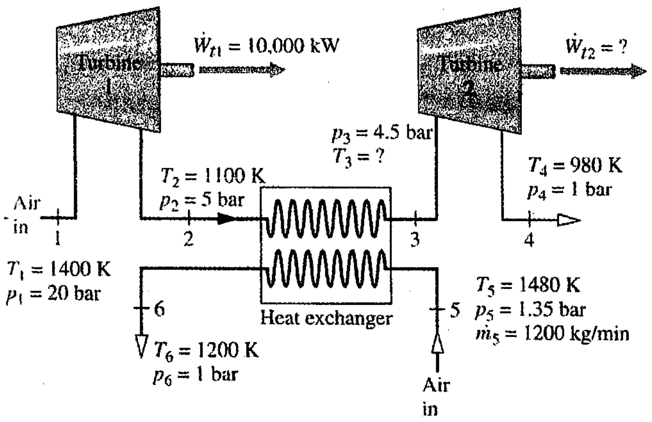
6. (20%) Air as an ideal gas flows through the turbine and heat exchanger arrangement as shown. Data for the two flow streams are shown on the figure. Heat transfer to the surroundings can be neglected, as can all kinetic and potential energy effects. Determine T_3, in K, and the power output of the second turbine, in kW, at steady state. The ideal gas properties of air are provided as follows.



T(K), h and u(kJ/kg), s° (kJ/kg · K)

				when $\Delta s = 0$[1]						when $\Delta s = 0$	
T	h	u	s°	p_r	v_r	T	h	u	s°	p_r	v_r
750	767.29	551.99	2.64737	37.35	57.63	1300	1395.97	1022.82	3.27345	330.9	11.275
760	778.18	560.01	2.66176	39.27	55.54	1320	1419.76	1040.88	3.29160	352.5	10.747
770	789.11	568.07	2.67595	41.31	53.39	1340	1443.60	1058.94	3.30959	375.3	10.247
780	800.03	576.12	2.69013	43.35	51.64	1360	1467.49	1077.10	3.32724	399.1	9.780
790	810.99	584.21	2.70400	45.55	49.86	1380	1491.44	1095.26	3.34474	424.2	9.337
800	821.95	592.30	2.71787	47.75	48.08	1400	1515.42	1113.52	3.36200	450.5	8.919
820	843.98	608.59	2.74504	52.59	44.84	1420	1539.44	1131.77	3.37901	478.0	8.526
840	866.08	624.95	2.77170	57.60	41.85	1440	1563.51	1150.13	3.39586	506.9	8.153
860	888.27	641.40	2.79783	63.09	39.12	1460	1587.63	1168.49	3.41247	537.1	7.801
880	910.56	657.95	2.82344	68.98	36.61	1480	1611.79	1186.95	3.42892	568.8	7.468
900	932.93	674.58	2.84856	75.29	34.31	1500	1635.97	1205.41	3.44516	601.9	7.152
920	955.38	691.28	2.87324	82.05	32.18	1520	1660.23	1223.87	3.46120	636.5	6.854
940	977.92	708.08	2.89748	89.28	30.22	1540	1684.51	1242.43	3.47712	672.8	6.569
960	1000.55	725.02	2.92128	97.00	28.40	1560	1708.82	1260.99	3.49276	710.5	6.301
980	1023.25	741.98	2.94468	105.2	26.73	1580	1733.17	1279.65	3.50829	750.0	6.046
1000	1046.04	758.94	2.96770	114.0	25.17	1600	1757.57	1298.30	3.52364	791.2	5.804
1020	1068.89	776.10	2.99034	123.4	23.72	1620	1782.00	1316.96	3.53879	834.1	5.574
1040	1091.85	793.36	3.01260	133.3	22.39	1640	1806.46	1335.72	3.55381	878.9	5.355
1060	1114.86	810.62	3.03449	143.9	21.14	1660	1830.96	1354.48	3.56867	925.6	5.147
1080	1137.89	827.88	3.05608	155.2	19.98	1680	1855.50	1373.24	3.58335	974.2	4.949
1100	1161.07	845.33	3.07732	167.1	18.896	1700	1880.1	1392.7	3.5979	1025	4.761
1120	1184.28	862.79	3.09825	179.7	17.886	1750	1941.6	1439.8	3.6336	1161	4.328
1140	1207.57	880.35	3.11883	193.1	16.946	1800	2003.3	1487.2	3.6684	1310	3.944
1160	1230.92	897.91	3.13916	207.2	16.064	1850	2065.3	1534.9	3.7023	1475	3.601
1180	1254.34	915.57	3.15916	222.2	15.241	1900	2127.4	1582.6	3.7354	1655	3.295
1200	1277.79	933.33	3.17888	238.0	14.470	1950	2189.7	1630.6	3.7677	1852	3.022
1220	1301.31	951.09	3.19834	254.7	13.747	2000	2252.1	1678.7	3.7994	2068	2.776
1240	1324.93	968.95	3.21751	272.3	13.069	2050	2314.6	1726.8	3.8303	2303	2.555
1260	1348.55	986.90	3.23638	290.8	12.435	2100	2377.4	1775.3	3.8605	2559	2.356
1280	1372.24	1004.76	3.25510	310.4	11.835	2150	2440.3	1823.8	3.8901	2837	2.175
						2200	2503.2	1872.4	3.9191	3138	2.012
						2250	2566.4	1921.3	3.9474	3464	1.864

Source: Tables A-22 are based on J. H. Keenan and J. Kaye, *Gas Tables*, Wiley, New York, 1945.

7. (15%) A thermocouple, with a spherical junction diameter D = 0.25 mm, is used for measuring the temperature of hot air flow in a circular duct. The convection heat transfer coefficient of the air flow are $h = 2.0\,(V/D)^{0.5}$, where D, h, and V (the average air flow velocity) are in m, W/m^2•K and m/s, respectively. The properties of the thermocouple junction are k = 30 W/m•K, ρ = 8500 kg/m^3, and c_p = 300 J/kg•K. Determine the minimum air flow velocity that the thermocouple can be used. If the maximum response time of the thermocouple to register 99% of the initial temperature difference is 5 s.

8. (10%) Consider a hemispherical furnace of diameter 4 m with a flat base. The dome of the furnace is black, and the base has the emissivity of 0.8. The base and the dome of the furnace are maintained at uniform temperature of 350K and 1000K, respectively. Determine the rate of radiation heat transfer from the dome to the base surface during steady operation.