94 學年度 工程與系統科學 系（所） 21 組碩士班入學考試

科目 熱力學 科目代碼 3302 共 5 頁 第 1 頁 *請在試卷【答案卷】內作答

1. Suppose that you are working in a company, your supervisor ask you chose one of the following three machines to improve its performance from the energy utilization point of view. Please give the first one you will pick, the second one, and the one you will leave for your advisor (15%). You need to specify the reasons why you make these choices.
   (a) A heat engine operates between 800 K and 300 K. It receives 100 kJ of energy from high temperature reservoir and rejects 50 kJ of waste heat to low temperature reservoir.
   (b) A refrigerator operates between –3 C and 37 C. It uses 50 kJ of work to deliver 100 kJ of energy to high temperature reservoir.
   (c) A heat pump operates between –23 C and 27 C. It takes 100 kJ of energy from low temperature reservoir and rejects 150 kJ of energy to high temperature reservoir.

2. (a) Describe the physical meaning of "exergy " or "availability" (5%).
(b) Please give the equation to calculate exergy or "availability" of an amount of energy Q associated with a thermal reservoir of temperature T and an environment temperature of T_o (4%). (c) When heat is transferred to a thermal reservoir with temperature lower than the environment, does its exergy or "availability" increase or decrease? Please explain your answer based on the physical meaning of exergy or "availability"(6%). Note: Exergy and availability are the same physical quantity. However, they have different name in some textbook.

3. An engineer designs a new heat pump, which uses 40 kW of power to extracts 400 kW from a environment at -3 C and delivers to a room with temperature of 27 C.
   (1) Please use *the Clausius Inequality* to determine whether the proposed heat pump is realistic (5%).
   (2) Please use *Principle of Entropy Increase* to verify your answer (5%).
   (3) Please use *Principle of Exergy Destruction* to verify your answer (5%)

4. Two constant pressure devices, each filled with 30 kg of air, have temperature of 1000 K and 300 K. A heat engine place between the two devices extracts heat from the high temperature devices, produces work, and rejects heat to the low temperature devices. Assume constant specific heats at room temperature. Determine (a) the final temperature of the devices (10%); (b) the maximum work that can be produced by the heat engine (5%). (If you do not know the answer of the first part use 548 K in your calculation of the second part). Constant pressure specific heat of air at room temperature is 1.005 kJ/kg K.
   Hint: Consider these two devices and the heat engine as the system of analysis. The final temperature of these two devices should be equal. To find the final temperature, write the entropy balance equation and set S_{gen} equals to zero. To deliver maximum of work, the heat engine is reversible.

5. Please plot the schematic diagram of (a) Co-Generation (3%), (b) Combined gas-vapor power cycles (4%), (c) Brayton cycle with intercooler, reheater, and regenerator (6%), (d) Rankine cycle with open feedwater heater (7%). Please label all the components in your plot. The name of the components has to be correct in order to get points.

6. A stationary power plant operating on a Brayton cycle has a pressure ratio of 11. The gas temperature is 300 K at the compressor inlet. The amount of heat added in the combustion chamber is 620 kJ/kg. Assuming a compressor isentropic efficiency of 80% and a turbine isentropic efficiency of 85%. Please determine:
   (1) The gas temperature at the exit of the compressor and turbine (4%).
   (2) The heat rejected per unit mass flow (4%).
   (3) The efficiency of the Brayton cycle (4%).
   (4) The second law efficiency of the Brayton cycle (4%); Hint: you need calculate the availability supplied in combustion chamber and availability recovered by the cycle.
   (5) If a regenerator with effectiveness of 90% is incorporated, how much input energy can be saved (4%)?

Some Useful Equations

Tds Relations:

$$Tds = du + Pdv, \quad Tds = dh - vdp$$

The entropy change of ideal gas:

$$s_2 - s_1 = \int_1^2 C_v(T)\frac{dT}{T} + R\ln\frac{v_2}{v_1}$$

$$s_2 - s_1 = \int_1^2 C_P(T)\frac{dT}{T} - R\ln\frac{P_2}{P_1}$$

$$s_2 - s_1 = s_2^o - s_1^o - R\ln\frac{P_2}{P_1}$$

Polytropic process relations:

$$Tv^{n-1} = \text{constant}$$

$$TP^{(1-n)/n} = \text{constant}$$

$$Pv^n = \text{constant}$$

Work for the Reversible Steady-State Process:

$$w = -\int_i^e v\,dp + \frac{V_i^2 - V_e^2}{2} + g(Z_i - Z_e)$$

Rate equation for entropy:

$$\dot{S}_{C.V.} = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \sum \frac{\dot{Q}_{C.V.}}{T} + \dot{S}_{gen}$$

Reversible work:

$$W_{C.V.}^{rev} = T_\circ(m_2 s_2 - m_1 s_1) - (m_2 e_2 - m_1 e_1) + T_\circ(m_e s_e - m_i s_i) - (m_e h_{Tot,e} - m_i h_{Tot,i}) + Q_{C.V.}\left(1 - \frac{T_\circ}{T_H}\right)$$

$$e = u + V^2/2 + gZ, \qquad h_{Tot} = h + V^2/2 + gZ$$

Availability (or exergy) :

$$\varphi = \left(h - T_\circ s + \frac{1}{2}V^2 + gZ\right) - (h_\circ - T_\circ s_\circ + gZ_\circ)$$

$$\phi = (e + P_\circ v - T_\circ s) - (e_\circ + P_\circ v_\circ - T_\circ s_\circ)$$

Ideal-Gas Properties of Air, Standard Entropy at 0.1-MPa (1-bar) Pressure

T (K)	u (kJ/kg)	h (kJ/kg)	s_T^0 (kJ/kg-K)	T (K)	u (kJ/kg)	h (kJ/kg)	s_T^0 (kJ/kg-K)
200	142.77	200.17	6.46260	1100	845.45	1161.18	8.24449
220	157.07	220.22	6.55812	1150	889.21	1219.30	8.29616
240	171.38	240.27	6.64535	1200	933.37	1277.81	8.34596
260	185.70	260.32	6.72562	1250	977.89	1336.68	8.39402
280	200.02	280.39	6.79998	1300	1022.75	1395.89	8.44046
290	207.19	290.43	6.83521	1350	1067.94	1455.43	8.48539
298.15	213.04	298.62	6.86305	1400	1113.43	1515.27	8.52891
300	214.36	300.47	6.86926	1450	1159.20	1575.40	8.57111
320	228.73	320.58	6.93413	1500	1205.25	1635.80	8.61208
340	243.11	340.70	6.99515	1550	1251.55	1696.45	8.65185
360	257.53	360.86	7.05276	1600	1298.08	1757.33	8.69051
380	271.99	381.06	7.10735	1650	1344.83	1818.44	8.72811
400	286.49	401.30	7.15926	1700	1391.80	1879.76	8.76472
420	301.04	421.59	7.20875	1750	1438.97	1941.28	8.80039
440	315.64	441.93	7.25607	1800	1486.33	2002.99	8.83516
460	330.31	462.34	7.30142	1850	1533.87	2064.88	8.86908
480	345.04	482.81	7.34499	1900	1581.59	2126.95	8.90219
500	359.84	503.36	7.38692	1950	1629.47	2189.19	8.93452
520	374.73	523.98	7.42736	2000	1677.52	2251.58	8.96611
540	389.69	544.69	7.46642	2050	1725.71	2314.13	8.99699
560	404.74	565.47	7.50422	2100	1774.06	2376.82	9.02721
580	419.87	586.35	7.54084	2150	1822.54	2439.66	9.05678
600	435.10	607.32	7.57638	2200	1871.16	2502.63	9.08573
620	450.42	628.38	7.61090	2250	1919.91	2565.73	9.11409
640	465.83	649.53	7.64448	2300	1968.79	2628.96	9.14189
660	481.34	670.78	7.67717	2350	2017.79	2692.31	9.16913
680	496.94	692.12	7.70903	2400	2066.91	2755.78	9.19586
700	512.64	713.56	7.74010	2450	2116.14	2819.37	9.22208
720	528.44	735.10	7.77044	2500	2165.48	2883.06	9.24781
740	544.33	756.73	7.80008	2550	2214.93	2946.86	9.27308
760	560.32	778.46	7.82905	2600	2264.48	3010.76	9.29790
780	576.40	800.28	7.85740	2650	2314.13	3074.77	9.32228
800	592.58	822.20	7.88514	2700	2363.88	3138.87	9.34625
850	633.42	877.40	7.95207	2750	2413.73	3203.06	9.36980
900	674.82	933.15	8.01581	2800	2463.66	3267.35	9.39297
950	716.76	989.44	8.07667	2850	2513.69	3331.73	9.41576
1000	759.19	1046.22	8.13493	2900	2563.80	3396.19	9.43818
1050	802.10	1103.48	8.19081	2950	2613.99	3460.73	9.46025
1100	845.45	1161.18	8.24449	3000	2664.27	3525.36	9.48198

The Isentropic Relative Pressure and Relative Volume Functions

T[K]	P_r	v_r	T[K]	P_r	v_r	T[K]	P_r	v_r
200	0.2703	493.47	700	23.160	20.155	1900	1327.5	0.95445
220	0.3770	389.15	720	25.742	18.652	1950	1485.8	0.87521
240	0.5109	313.27	740	28.542	17.289	2000	1658.6	0.80410
260	0.6757	256.58	760	31.573	16.052	2050	1847.1	0.74012
280	0.8756	213.26	780	34.851	14.925	2100	2052.1	0.68242
290	0.9899	195.36	800	38.388	13.897	2150	2274.8	0.63027
298.15	1.0907	182.29	850	48.468	11.695	2200	2516.2	0.58305
300	1.1146	179.49	900	60.520	9.9169	2250	2777.5	0.54020
320	1.3972	152.73	950	74.815	8.4677	2300	3059.9	0.50124
340	1.7281	131.20	1000	91.651	7.2760	2350	3364.6	0.46576
360	2.1123	113.65	1050	111.35	6.2885	2400	3693.0	0.43338
380	2.5548	99.188	1100	134.25	5.4641	2450	4046.2	0.40378
400	3.0612	87.137	1150	160.73	4.7714	2500	4425.8	0.37669
420	3.6373	77.003	1200	191.17	4.1859	2550	4833.0	0.35185
440	4.2892	68.409	1250	226.02	3.6880	2600	5269.5	0.32903
460	5.0233	61.066	1300	265.72	3.2626	2650	5736.7	0.30805
480	5.8466	54.748	1350	310.74	2.8971	2700	6236.2	0.28872
500	6.7663	49.278	1400	361.62	2.5817	2750	6769.7	0.27089
520	7.7900	44.514	1450	418.89	2.3083	2800	7338.7	0.25443
540	8.9257	40.344	1500	483.16	2.0703	2850	7945.1	0.23921
560	10.182	36.676	1550	554.96	1.8625	2900	8590.7	0.22511
580	11.568	33.436	1600	634.97	1.6804	2950	9277.2	0.21205
600	13.092	30.561	1650	723.86	1.52007	3000	10007.	0.19992
620	14.766	28.001	1700	822.33	1.37858			
640	16.598	25.713	1750	931.14	1.25330			
660	18.600	23.662	1800	1051.05	1.14204			
680	20.784	21.818	1850	1182.9	1.04294			
700	23.160	20.155	1900	1327.5	0.95445			

The relative pressure and relative volume are temperature functions calculated with two scaling constants A_1, A_2.

$$P_r = \exp[s_T^0/R - A_1]; \qquad v_r = A_2 T/P_r$$

such that for an isentropic process ($s_1 = s_2$)

$$\frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}} = \frac{e^{s_{T2}^0/R}}{e^{s_{T1}^0/R}} \approx \left(\frac{T_2}{T_1}\right)^{C_p/R} \quad \text{and} \quad \frac{v_2}{v_1} = \frac{v_{r2}}{v_{r1}} \approx \left(\frac{T_2}{T_1}\right)^{C_v/R}$$

where the near equalities are for the constant heat capacity approximation.