Thermodynamics

Problem 1 (20%)

Describe briefly the following energy systems: (a) the combined cycle (b) fuel cell, (c) batteries, and (d) the cogeneration.

Problem 2 (20%)

The power required to operate a steady-state compressor is 3.56 Kw. Air enters the compressor at 1 bar and 300 K at a rate of 1 kg/min and leaves at 7 bars and 500 K. Determine (a) the rate of heat transfer, in kJ/h, (b) the entropy change of the air, in Kj/(min K), and (c) the entropy change of the environment which receives the heat transferred at 288 K, in kJ/(min K). (d) Is the process reversible, irreversible, or impossible?

problem 3 (20%)

At what temperature, will CO be 10% of the total moles of products if CO is burned with the stoichiometric amount of O_2 at 2-atm pressure?

Problem 4 (20%)

(a) Derive the expression $c_p - c_v = -T(\partial v/\partial T)_p^2(\partial P/\partial v)_T$. (b) At 500 K the values of v, β, and K_T for solid copper are 7.115 mL/gmol, 54.2×10^{-6} K^{-1}, and 0.837×10^{-7} cm^2/N, respectively. Determine the value of $c_p - c_v$ in J/gmol C. ($\beta = (1/v)(\partial v/\partial T)_p$, $K_T = -(1/v)(\partial v/\partial P)_T$).

Problem 5 (20%)

A Carnot heat engine receive 90 kJ from a reservoir at 900 K. It rejects heat to the environment at 300 K. One-fifth of its work output is used to derive a Carnot refrigerator. The refrigerator rejects 60 kJ to the environment at 300 K. Find (a) the work output of the heat engine, (b) the efficiency of the heat engine, (c) the temperature of the low-temperature reservoir for the refrigerator, and (d) the coefficient of performance (COP) of the refrigerator.

rsical constants and conversion factors

Physical constants

gadro's number	$N_A = 6.023 \times 10^{26}$ atoms/kgmol
ersal gas constant	$R_u = 0.08205$ L·atm/(gmol·K)
	$= 8.314$ kJ/(kgmol·K)
	$= 0.08314$ bar·m³/(kgmol·K)
	$= 8.314$ kPa·m³/(kgmol·K)
ck's constant	$h = 6.626 \times 10^{-34}$ J·s/molecule
tzmann's constant	$k = 1.380 \times 10^{-23}$ J/(K·molecule)
ed of light	$c = 2.988 \times 10^{10}$ cm/s
dard gravity	$g = 9.80665$ m/s²

Conversion factors

gth	1 cm = 0.3937 in = 10^4 μm = 10^8 Å
	1 km = 0.6215 mi = 3281 ft
	1 kg = 2.205 lb_m
sure	1 N = 1 kg·m/s² = 0.2248 lb_f
	1 bar = 10^5 N/m² = 0.9869 atm
	= 100 kPa
	1 torr = 1 mmHg at 0°C = 1.333 mbar
	= 1.933×10^{-2} psi
	1 mbar = 0.402 inH_2O
ume	1 L = 0.0353 ft³ = 0.2642 gal = 61.025 in³ = 10^{-3} m³
sity	1 g/cm³ = 1 kg/L = 62.4 lb_m/ft^3 = 10^3 kg/m³
rgy	1 J = 1 N·m = 1 V·C
	= 0.7375 ft·lb_f = 10 bar·cm³ = 0.624 × 10^{19} eV
	1 kJ = 0.948 Btu = 737.6 ft·lb_f = 10^{-2} bar·m³
	1 kJ/kg = 0.431 Btu/lb
wer	1 W = 1 J/s = 3.413 Btu/h
	1 kW = 1.3405 hp = 737.3 ft·lb_f/s
ocity	1 m/s = 2.237 mi/h = 3.60 km/h = 3.281 ft/s
ecific heat	1 kJ/(kg·K) = 0.2389 Btu/(lb_m·°F)
mperature	T(K) = ⅝[T(°F) + 459.67] = T(°C) + 273.15 = T(°R)/1.8

rived units and common multipliers

1. Some SI derived units

ical quantity	Unit	Symbol	Definition
rce	newton	N	1 kg·m/s²
ure	pascal	Pa	1 kg/m·s² (= 1 N/m²)
	bar	bar	10^5 kg/m·s² (= 10^5 N/m²)
gy	joule	J	1 kg·m²/s² (= 1 N·m)
	watt	W	1 kg·m²/s³ (= 1 J/s)
ric quantity	coulomb	C	1 A·s
ric potential	volt	V	1 kg·m²/(A·s³) (= 1 A·Ω)
ctance			
ric resistance	ohm	Ω	1 kg·m²/(A²·s³) (= 1 V/A)
ric capacitance	farad	F	1 A²·s⁴/(kg·m²) (= 1 C/V)

2. Names and symbols for common multipliers of SI units

ltiplier	Prefix	Symbol
	giga	G
	mega	M
	kilo	k
	deci	d
	centi	c
	milli	m
	micro	μ
	nano	n

Logarithms to the base 10 of the equilibrium constant K_p

$K_p = \dfrac{(p_E)^{\nu_E}(p_F)^{\nu_F}}{(p_A)^{\nu_A}(p_B)^{\nu_B}}$ for the reaction $\nu_A A + \nu_B B \rightleftharpoons \nu_E E + \nu_F F$

Numbered reactions:

(1) $H_2 \rightleftharpoons 2H$
(2) $O_2 \rightleftharpoons 2O$
(3) $N_2 \rightleftharpoons 2N$
(4) $\frac{1}{2}O_2 + \frac{1}{2}N_2 \rightleftharpoons NO$
(5) $H_2O \rightleftharpoons H_2 + \frac{1}{2}O_2$
(6) $H_2O \rightleftharpoons OH + \frac{1}{2}H_2$
(7) $CO_2 \rightleftharpoons CO + \frac{1}{2}O_2$
(8) $CO_2 + H_2 \rightleftharpoons CO + H_2O$

Temp., K	log K_p values for reactions numbered above							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
298	−71.224	−81.208	−159.600	−15.171	−40.048	−46.054	−45.066	−5.018
500	−40.316	−45.880	−92.672	−8.783	−22.886	−26.130	−25.025	−2.139
1000	−17.292	−19.614	−43.056	−4.062	−10.062	−11.280	−10.221	−0.159
1200	−13.414	−15.208	−34.754	−3.275	−7.899	−8.789	−7.764	+0.135
1400	−10.630	−12.054	−28.812	−2.712	−6.347	−7.003	−6.014	+0.333
1600	−8.532	−9.684	−24.350	−2.290	−5.180	−5.662	−4.706	+0.474
1700	−7.666	−8.706	−22.512	−2.116	−4.699	−5.109	−4.169	+0.530
1800	−6.896	−7.836	−20.874	−1.962	−4.270	−4.617	−3.693	+0.577
1900	−6.204	−7.058	−19.410	−1.823	−3.886	−4.177	−3.267	+0.619
2000	−5.580	−6.356	−18.092	−1.699	−3.540	−3.780	−2.884	+0.656
2100	−5.016	−5.720	−16.898	−1.586	−3.227	−3.422	−2.539	+0.688
2200	−4.502	−5.142	−15.810	−1.484	−2.942	−3.095	−2.226	+0.716
2300	−4.032	−4.614	−14.818	−1.391	−2.682	−2.798	−1.940	+0.742
2400	−3.600	−4.130	−13.908	−1.305	−2.443	−2.525	−1.679	+0.764
2500	−3.202	−3.684	−13.070	−1.227	−2.224	−2.274	−1.440	+0.784
2600	−2.836	−3.272	−12.298	−1.154	−2.021	−2.042	−1.219	+0.802
2700	−2.494	−2.892	−11.580	−1.087	−1.833	−1.828	−1.015	+0.818
2800	−2.178	−2.536	−10.914	−1.025	−1.658	−1.628	−0.825	+0.833
2900	−1.882	−2.206	−10.294	−0.967	−1.495	−1.442	−0.649	+0.846
3000	−1.606	−1.898	−9.716	−0.913	−1.343	−1.269	−0.485	+0.858
3100	−1.348	−1.610	−9.174	−0.863	−1.201	−1.107	−0.332	+0.869
3200	−1.106	−1.340	−8.664	−0.815	−1.067	−0.955	−0.189	+0.878
3300	−0.878	−1.086	−8.186	−0.771	−0.942	−0.813	−0.054	+0.888
3400	−0.664	−0.846	−7.736	−0.729	−0.824	−0.679	+0.071	+0.895
3500	−0.462	−0.620	−7.312	−0.690	−0.712	−0.552	+0.190	+0.902

Source: Based on data from the JANAF Tables, NSRDS-NBS-37, 1971, and revisions published in *Journal of Physical and Chemical Data* through 1982.

Ideal-gas properties of air

T, K; *h*, kJ/kg; *u*, kJ/kg; p_r, kJ/(kg·K)

T	h	p_r	u	v_r	s°	T	h	p_r	u	v_r	s°
200	199.97	0.3363	142.56	1707.	1.29559	460	462.02	6.245	329.97	211.4	2.13407
210	209.97	0.3987	149.69	1512.	1.34444	470	472.24	6.742	337.32	200.1	2.15604
220	219.97	0.4690	156.82	1346.	1.39105	480	482.49	7.268	344.70	189.5	2.17760
230	230.02	0.5477	164.00	1205.	1.43557	490	492.74	7.824	352.08	179.7	2.19876
240	240.02	0.6355	171.13	1084.	1.47824	500	503.02	8.411	359.49	170.6	2.21952
250	250.05	0.7329	178.28	979.	1.51917	510	513.32	9.031	366.92	162.1	2.23993
260	260.09	0.8405	185.45	887.8	1.55848	520	523.63	9.684	374.36	154.1	2.25997
270	270.11	0.9590	192.60	808.0	1.59634	530	533.98	10.37	381.84	146.7	2.27967
280	280.13	1.0889	199.75	738.0	1.63279	540	544.35	11.10	389.34	139.7	2.29906
285	285.14	1.1584	203.33	706.1	1.65055	550	554.74	11.86	396.86	133.1	2.31809
290	290.16	1.2311	206.91	676.1	1.66802	560	565.17	12.66	404.42	127.0	2.33685
295	295.17	1.3068	210.49	647.9	1.68515	570	575.59	13.50	411.97	121.2	2.35531
300	300.19	1.3860	214.07	621.2	1.70203	580	586.04	14.38	419.55	115.7	2.37348
305	305.22	1.4686	217.67	596.0	1.71865	590	596.52	15.31	427.15	110.6	2.39140
310	310.24	1.5546	221.25	572.3	1.73498	600	607.02	16.28	434.78	105.8	2.40902
315	315.27	1.6442	224.85	549.8	1.75106	610	617.53	17.30	442.42	101.2	2.42644
320	320.29	1.7375	228.42	528.6	1.76690	620	628.07	18.36	450.09	96.92	2.44356
325	325.31	1.8345	232.02	508.4	1.78249	630	638.63	19.84	457.78	92.84	2.46048
330	330.34	1.9352	235.61	489.4	1.79783	640	649.22	20.64	465.50	88.99	2.47716
340	340.42	2.149	242.82	454.1	1.82790	650	659.84	21.86	473.25	85.34	2.49364
350	350.49	2.379	250.02	422.2	1.85708	660	670.47	23.13	481.01	81.89	2.50985
360	360.58	2.626	257.24	393.4	1.88543	670	681.14	24.46	488.81	78.61	2.52589
370	370.67	2.892	264.46	367.2	1.91313	680	691.82	25.85	496.62	75.50	2.54175
380	380.77	3.176	271.69	343.4	1.94001	690	702.52	27.29	504.45	72.56	2.55731
390	390.88	3.481	278.93	321.5	1.96633	700	713.27	28.80	512.33	69.76	2.57277
400	400.98	3.806	286.16	301.6	1.99194	710	724.04	30.38	520.23	67.07	2.58810
410	411.12	4.153	293.43	283.3	2.01699	720	734.82	32.02	528.14	64.53	2.60319
420	421.26	4.522	300.69	266.6	2.04142	730	745.62	33.72	536.07	62.13	2.61803
430	431.43	4.915	307.99	251.1	2.06533	740	756.44	35.50	544.02	59.82	2.63280
440	441.61	5.332	315.30	236.8	2.08870	750	767.29	37.35	551.99	57.63	2.64737
450	451.80	5.775	322.62	223.6	2.11161	760	778.18	39.27	560.01	55.54	2.66176