

273.15 K = 0°C. Molecular weights of air and water are 28.97 kg/kmol and 18 kg/kmol, respectively. Universal gas constant = 8.314 kJ/kmol·K. 1 ton = 1000 kg.

1. A regenerative power cycle with one open feedwater heater is given in Figure 1 where the operation conditions are summarized in Table 1. For a net power of 248 MW, determine (a) the temperature T_2 in °C, (b) the quality x_3 , (c) the temperature T_4 , in °C, (d) the temperature T_5 , in °C, (e) the temperature T_6 in °C, (f) the temperature T_7 in °C, (g) the fraction of the total flow not entering the second turbine y , (h) thermal efficiency η , and (i) the mass flow rate of water \dot{m} , in ton/hr. (36%)

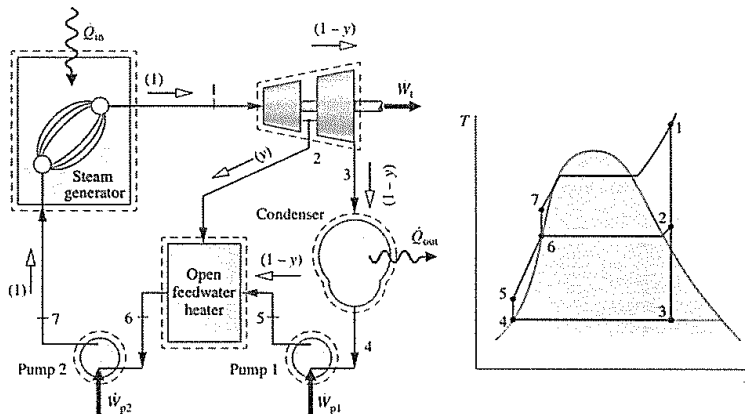


Fig. 1: A regenerative power cycle

Table 1:
Operation Conditions

Location	p (MPa)	T (°C)
1	10	560
2	1	T_2
3	0.01	T_3
4	0.01	T_4
5	1	T_5
6	1	T_6
7	10	T_7

2. A closed and rigid vessel containing air-water vapor mixture undergoes a cooling process with the volume of 2.172 m³, Fig.2. The operation conditions are summarized in Table 2. The dew point temperature of the initial state is 99.63°C. Air behaves as an ideal gas with specific heat ratio of 1.4. Determine (a) the initial temperature of mixture T_1 , in °C, (b) the initial pressure of mixture p_1 , in bar, (c) the mass of vapor, in kg, (d) the mass of dry air, in kg, (e) the temperature of mixture T_2 when water vapor starts to condensate, in °C, (f) the pressure of the mixture p_2 , in bar, as the mixture temperature reaches T_2 , (g) the heat transfer during the cooling process, in kJ, (h) the entropy production during the cooling process, in kJ/K, if the vessel boundary always keeps at a constant temperature of T_2 . (32%)

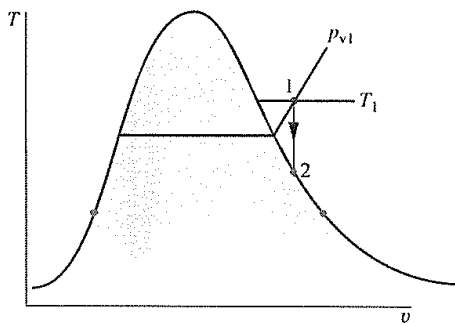


Fig. 2: A cooling process

Table 2:
Operation Conditions

Location	1	2
T (°C)	T_1	T_2
p (°C)	p_1	p_2
Relative Humidity	6.435%	—
Humidity Ratio	62.2%	—

3. For a closed simple compressible system operating with air as an ideal gas with molecular weight M as well as constant specific heats c_p and c_v where $k = c_p/c_v$. The temperature T , pressure p , specific volume v and specific entropy s of two equilibrium states of this system are given as (T_1, p_1, v_1, s_1) and (T_2, p_2, v_2, s_2) , respectively. The universal gas constant is \bar{R} and $R = \bar{R}/M$. Please derive the following relations. (32%)
 - (a) $Tds = du + pdv$ and $Tds = dh - vdp$
 - (b) $s_2 - s_1 = c_v \ln(T_2/T_1) + R \ln(v_2/v_1)$ and $s_2 - s_1 = c_p \ln(T_2/T_1) - R \ln(p_2/p_1)$
 - (c) For an isentropic process, $(T_2/T_1)^k = (p_2/p_1)^{k-1}$ and $T_2/T_1 = (v_1/v_2)^{k-1}$
 - (d) The thermal efficiency $\eta = 1 - r^{(1-k)}$ of a cold air-standard Otto cycle with the compression ratio r where its processes are modeled by a closed simple compressible system.

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Properties of Saturated Water (Liquid-Vapor): Temperature Table

Temp. °C	Press. bar	Specific Volume m ³ /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg·K		Temp. °C
		Sat. Liquid v _f	Sat. Vapor v _g	Sat. Liquid u _f	Sat. Vapor u _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Sat. Vapor s _g	
.01	0.00611	1.0002	206.136	0.00	2375.3	0.01	2501.3	0.0000	9.1562	.01	
4	0.00813	1.0001	157.232	16.77	2380.9	16.78	2491.9	2508.7	0.0610	9.0514	4
5	0.00872	1.0001	147.120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257	5
6	0.00935	1.0001	137.734	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003	6
8	0.01072	1.0002	120.917	33.59	2386.4	33.60	2482.5	2516.1	0.1212	8.9501	8
10	0.01228	1.0004	106.379	42.00	2389.2	42.01	2477.7	2519.8	0.1510	8.9008	10
11	0.01312	1.0004	99.857	46.20	2390.5	46.20	2475.4	2521.6	0.1658	8.8765	11
12	0.01402	1.0005	93.784	50.41	2391.9	50.41	2473.0	2523.4	0.1806	8.8524	12
13	0.01497	1.0007	88.124	54.60	2393.3	54.60	2470.7	2525.3	0.1953	8.8285	13
14	0.01598	1.0008	82.848	58.79	2394.7	58.80	2468.3	2527.1	0.2099	8.8048	14
15	0.01705	1.0009	77.926	62.99	2396.1	62.99	2465.9	2528.9	0.2245	8.7814	15
16	0.01818	1.0011	73.333	67.18	2397.4	67.19	2463.6	2530.8	0.2390	8.7582	16
17	0.01938	1.0012	69.044	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351	17
18	0.02064	1.0014	65.038	75.57	2400.2	75.58	2458.8	2534.4	0.2679	8.7123	18
19	0.02198	1.0016	61.293	79.76	2401.6	79.77	2456.5	2536.2	0.2823	8.6897	19
20	0.02339	1.0018	57.791	83.95	2403.0	83.96	2454.1	2538.1	0.2966	8.6672	20
21	0.02487	1.0020	54.514	88.14	2404.3	88.14	2451.8	2539.9	0.3109	8.6450	21
22	0.02645	1.0022	51.447	92.33	2405.7	92.33	2449.4	2541.7	0.3251	8.6229	22
23	0.02810	1.0024	48.574	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011	23
24	0.02985	1.0027	45.883	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794	24
25	0.03169	1.0029	43.360	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580	25
26	0.03363	1.0032	40.994	109.06	2411.1	109.07	2439.9	2549.0	0.3814	8.5367	26
27	0.03567	1.0035	38.774	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156	27
28	0.03782	1.0037	36.690	117.42	2413.9	117.43	2435.2	2552.6	0.4093	8.4946	28
29	0.04008	1.0040	34.733	121.60	2415.2	121.61	2432.8	2554.5	0.4231	8.4739	29
30	0.04246	1.0043	32.894	125.78	2416.6	125.79	2430.5	2556.3	0.4369	8.4533	30
31	0.04496	1.0046	31.165	129.96	2418.0	129.97	2428.1	2558.1	0.4507	8.4329	31
32	0.04759	1.0050	29.540	134.14	2419.3	134.15	2425.7	2559.9	0.4644	8.4127	32
33	0.05034	1.0053	28.011	138.32	2420.7	138.33	2423.4	2561.7	0.4781	8.3927	33
34	0.05324	1.0056	26.571	142.50	2422.0	142.50	2421.0	2563.5	0.4917	8.3728	34
35	0.05628	1.0060	25.216	146.67	2423.4	146.68	2418.6	2565.3	0.5053	8.3531	35
36	0.05947	1.0063	23.940	150.85	2424.7	150.86	2416.2	2567.1	0.5188	8.3336	36
38	0.06632	1.0071	21.602	159.20	2427.4	159.21	2411.5	2570.7	0.5458	8.2950	38
40	0.07384	1.0078	19.523	167.56	2430.1	167.57	2406.7	2574.3	0.5725	8.2570	40
45	0.09593	1.0099	15.258	188.44	2436.8	188.45	2394.8	2583.2	0.6387	8.1648	45

Properties of Saturated Water (Liquid-Vapor): Pressure Table

Temp. °C	Press. bar	Specific Volume m ³ /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg·K		Temp. °C
		Sat. Liquid v _f	Sat. Vapor v _g	Sat. Liquid u _f	Sat. Vapor u _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Sat. Vapor s _g	
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0388	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0414	1.869	405.06	2502.6	405.15	2267.0	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2262.5	2675.6	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2209.9	2706.7	1.5301	7.1171	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2548.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7746	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2109.5	2748.7	1.8607	6.8212	5.00
6.00	158.0	1.1006	0.3157	669.90	2567.4	670.52	2086.3	2756.9	1.9312	6.7600	6.00
7.00	163.9	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1973.2	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1930.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1881.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1849.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1793.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1741.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2777.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2768.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2757.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2744.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2730.6	3.4295	5.5527	110.

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Temp. °C	Press. bar	Specific Volume m ³ /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg·K		Temp. °C
		Sat. Liquid v _f	Sat. Vapor v _g	Sat. Liquid u _f	Sat. Vapor u _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Sat. Vapor s _g	
50	.1235	1.0121	12.032	209.32	2443.5	209.33	2382.7	2592.1	.7038	8.0763	50
55	.1576	1.0146	9.568	230.21	2450.1	230.23	2370.7	2600.9	.7679	7.9913	55
60	.1994	1.0172	7.671	251.11	2456.6	251.13	2358.5	2609.6	.8312	7.9096	60
65	.2503	1.0199	6.197	272.02	2463.1	272.06	2346.2	2618.3	.8935	7.8310	65
70	.3119	1.0228	5.042	292.95	2469.6	292.98	2333.8	2626.8	.9529	7.7553	70
75	.3858	1.0259	4.131	313.90	2475.9	313.93	2321.4	2635.3	1.0155	7.6824	75
80	.4739	1.0291	3.407	334.86	2482.2	334.91	2308.8	2643.7	1.0753	7.6122	80
85	.5783	1.0325	2.828	355.84	2488.4	355.90	2296.0	2651.9	1.1343	7.5445	85
90	.7014	1.0360	2.361	376.85	2494.5	376.92	2283.2	2660.1	1.1925	7.4791	90
95	.8455	1.0397	1.982	397.88	2500.6						

Properties of Superheated Water Vapor

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 0.05 bar, 0.10 bar, 0.20 bar, and 0.30 bar.

(Continued)

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 5.0 bar, 7.0 bar, 10.0 bar, and 15.0 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 0.70 bar, 1.0 bar, 1.0 bar, and 1.5 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 10.0 bar, 15.0 bar, 20.0 bar, and 30.0 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 1.5 bar, 3.0 bar, 3.0 bar, and 4.0 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 20.0 bar, 30.0 bar, 40.0 bar, and 60.0 bar.

(Continued)

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 40 bar, 60 bar, 80 bar, and 100 bar.

(Continued)

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 200 bar, 300 bar, 400 bar, and 500 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 80 bar, 100 bar, 100 bar, and 200 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 100 bar, 200 bar, 200 bar, and 300 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 120 bar, 140 bar, 140 bar, and 280 bar.

Table with 4 columns (T, v, u, h, s) and 4 rows for pressures p = 280 bar, 320 bar, 320 bar, and 400 bar.