NATIONAL EXAMINATIONS - December 2016

04-BS-10, Thermodynamics

3 Hours Duration

NOTES:

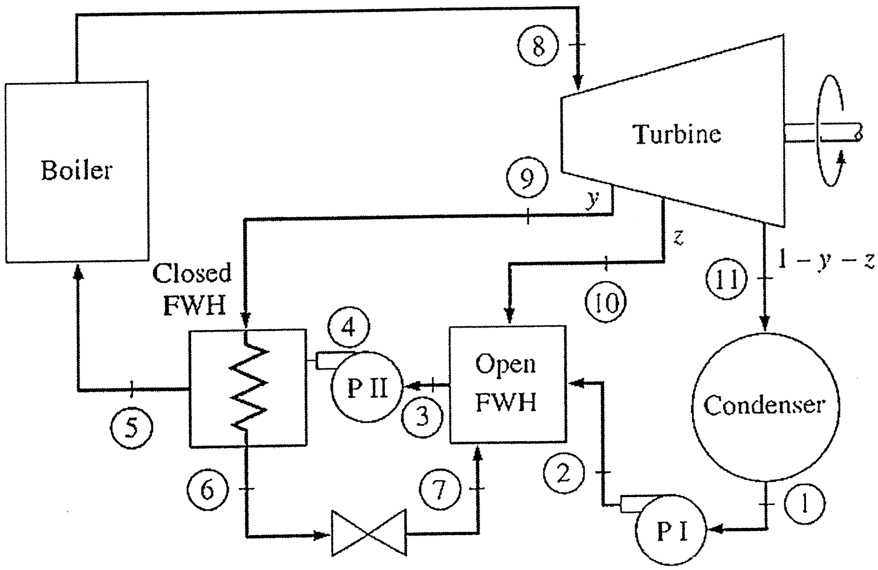
1. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.
2. Any one of the approved calculator models is permitted. This is a "Closed-Book" examination with one 8.5×11 inch sheet of notes (both sides) allowed.
3. Property tables and charts are provided where necessary. **Interpolation is not necessary. The closest tabular value may be used.**
4. **Two** questions from part "A" plus **four** questions from part "B" (a total of **six** questions) constitutes a complete paper. Unless clearly indicated otherwise by you, only the first two questions from part "A" and the first four questions from part "B" that you answered will be marked.
5. The mark associated with each question is specified.

PART A. DO ONLY TWO OF QUESTIONS 1, 2, or 3

(Each question is worth **20 marks**)

1. Consider an ideal regenerative vapor power cycle with two feedwater heaters, a closed one and an open one as shown in the figure. Steam enters the first stage turbine at 12.5 MPa and 550°C, and expands to 0.8 MPa. A fraction of the steam (y) is extracted at 0.8 MPa and fed to the closed feedwater heater. The remainder of the steam expands through the second stage of the turbine to 0.3 MPa, where an additional amount (fraction z) is extracted and fed into the open feedwater heater, which operates at 0.3 MPa. The remaining steam expands through the third stage of the turbine and exits at the condenser pressure of 10 kPa. Feedwater leaves the closed feedwater heater at 170°C and 12.5 MPa, and condensate exiting as saturated liquid at 0.8 MPa is trapped in the open feedwater heater. Saturated liquid at 0.3 MPa leaves the open feedwater heater. The net power output of the cycle is 150 MW. Sketch the cycle on a T-s diagram with respect to saturation lines and determine

(a) the net power output, in kJ/kg,
(b) the mass flow rate of stream entering the first stage turbine, in kg/h, and
(c) the thermal efficiency of the cycle.



2. A vapour-compression heat pump with a heating capacity of 500 kJ/min is driven by a power cycle with a thermal efficiency of 25%. For the heat pump, Refrigerant 134a is compressed from saturated vapour at -12°C to the condenser pressure of 1 MPa. The isentropic compressor efficiency is 80%. Liquid enters the expansion valve at 0.96 MPa and 34°C. For the power cycle, 80% of the heat rejected is transferred to the heated space. Determine

   (a) the power input to the heat pump compressor, in kW,
   (b) the coefficient of performance of the heat pump,
   (c) the entropy generation rate in the heat pump compressor, in kJ/K·s, and
   (d) the rate of exergy destruction in the heat pump compressor, in kJ/s, if T_o = 15°C.

3. Consider a Brayton cycle with reheat using air as the working fluid. Air enters the compressor at 100 kPa and 300 K. Air enters the turbine at 400 kPa and 1200 K, and expands to 100 kPa in two stages. Between the stages, air is reheated at a constant pressure of 200 kPa to 1200 K. Each turbine stage has an isentropic efficiency of 88% and compressor has an isentropic efficiency of 90%. Assume a source temperature of 1200 K and a sink temperature of 300 K. Show the cycle on a T-s diagram. Assume variable specific heats for air and determine

   (a) the net work output, in kJ/kg,
   (b) the thermal efficiency of the cycle,
   (c) the increase (%) in net work output as compared to a single stage of expansion with no reheat, and
   (d) the second law efficiency of the cycle.

PART B. DO ONLY FOUR OF QUESTIONS 4, 5, 6, 7, 8 or 9

(Each question is worth **15 marks**)

4. Air enters a steady-flow turbine. The conditions of the air entering and leaving the turbine are as follows: inlet, 300 kPa and 52°C; exit, 100 kPa and 12°C. The mass flow rate is 10 kg/s. Heat transfer from the turbine to the surroundings and the kinetic and potential energy effects are negligible. Calculate the power developed by the turbine. Determine whether the process in the turbine is reversible. If not, determine the isentropic efficiency of the turbine.

5. A rigid tank initially contains 0.5 kg of steam at 700 kPa and 320°C and is connected through an insulated valve to a steam supply line that supplies steam at a constant condition of 1.5 MPa and 320°C. The valve is opened so that the supply steam flows slowly into the tank until the pressure and temperature inside are 1.0 MPa and 320°C. Determine (a) the final mass of steam in the tank and (b) the heat transfer to or from the steam in the tank during the process.

6. An air-standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 95 kPa and 300 K. Accounting for the variation of specific heats with temperature, determine (a) the temperature after the heat-addition process, (b) the thermal efficiency and (c) the mean effective pressure.

7. A mixture of 80% N_2, and 20% CO_2 gases (by mole numbers), is compressed isentropically in a compressor. The mixture enters the compressor at 100 kPa and 1000 K and leaves at 500 kPa. Assume constant specific heats at room temperature (300 K). Treat the mixture as an ideal gas. Determine the work input to the compressor per unit mass of the mixture.

8. Air expands at a mass flow rate of 10 kg/s through a turbine from 500 kPa, 900 K to 100 kPa, 600 K. The inlet velocity is small compared to the exit velocity of 100 m/s. The turbine operates at steady state. Heat transfer from the turbine to the surroundings and potential energy effects are negligible. Calculate

   (a) the power developed by the turbine, in kW, and
   (b) the turbine exit area, in m^2.

9. 1.5 kg of air executes a Carnot power cycle having a thermal efficiency of 50%. The heat transfer to the air during the isothermal expansion is 40 kJ. At the beginning of the isothermal expansion, the pressure is 700 kPa and the volume is 0.12 m^3. Sketch the cycle on *p-v* diagram and determine

   (a) the maximum and minimum temperatures for the cycle, in K,
   (b) the volume at the end of the isothermal expansion, in m^3, and
   (c) the work and heat transfer for each of the four processes, in kJ.

APPENDIX – TABLES AND CHART

TABLE A-1
Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass kg/kmol	R kJ/(kg · K)*	Temperature K	Pressure MPa	Volume m³/kmol
Ammonia	NH_3	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Bromine	Br_2	159.808	0.0520	584	10.34	0.1355
Carbon dioxide	CO_2	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Chlorine	Cl_2	70.906	0.1173	417	7.71	0.1242
Deuterium (normal)	D_2	4.00	2.0785	38.4	1.66	—
Helium	He	4.003	2.0769	5.3	0.23	0.0578
Hydrogen (normal)	H_2	2.016	4.1240	33.3	1.30	0.0649
Krypton	Kr	83.80	0.09921	209.4	5.50	0.0924
Neon	Ne	20.183	0.4119	44.5	2.73	0.0417
Nitrogen	N_2	28.013	0.2968	126.2	3.39	0.0899
Nitrous oxide	N_2O	44.013	0.1889	309.7	7.27	0.0961
Oxygen	O_2	31.999	0.2598	154.8	5.08	0.0780
Sulfur dioxide	SO_2	64.063	0.1298	430.7	7.88	0.1217
Water	H_2O	18.015	0.4615	647.3	22.09	0.0568
Xenon	Xe	131.30	0.06332	289.8	5.88	0.1186
Benzene	C_6H_6	78.115	0.1064	562	4.92	0.2603
n-Butane	C_4H_{10}	58.124	0.1430	425.2	3.80	0.2547
Carbon tetrachloride	CCl_4	153.82	0.05405	556.4	4.56	0.2759
Chloroform	$CHCl_3$	119.38	0.06964	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl_2F_2	120.91	0.06876	384.7	4.01	0.2179
Dichlorofluoromethane	$CHCl_2F$	102.92	0.08078	451.7	5.17	0.1973
Ethane	C_2H_6	30.070	0.2765	305.5	4.88	0.1480
Ethyl alcohol	C_2H_5OH	46.07	0.1805	516	6.38	0.1673
Ethylene	C_2H_4	28.054	0.2964	282.4	5.12	0.1242
n-Hexane	C_6H_{14}	86.178	0.09647	507.9	3.03	0.3677
Methane	CH_4	16.043	0.5182	191.1	4.64	0.0993
Methyl alcohol	CH_3OH	32.042	0.2595	513.2	7.95	0.1180
Methyl chloride	CH_3Cl	50.488	0.1647	416.3	6.68	0.1430
Propane	C_3H_8	44.097	0.1885	370	4.26	0.1998
Propene	C_3H_6	42.081	0.1976	365	4.62	0.1810
Propyne	C_3H_4	40.065	0.2075	401	5.35	—
Trichlorofluoromethane	CCl_3F	137.37	0.06052	471.2	4.38	0.2478
Air	—	28.97	0.2870	—	—	—

*The unit kJ/(kg · K) is equivalent to kPa · m³/(kg · K). The gas constant is calculated from $R = R_u/M$, where $R_u = 8.314$ kJ/(kmol · K) and M is the molar mass.

Source: Gordon J. Van Wylen and Richard E. Sonntag, *Fundamentals of Classical Thermodynamics*, English/SI Version, 3d ed., Wiley, New York, 1986, p. 685, table A.6SI. Originally published in K. A. Kobe and R. E. Lynn, Jr., *Chemical Review*, vol. 52, pp. 117–236, 1953.

TABLE A-4

Saturated water—Temperature table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/(kg · K)		
Temp., T °C	Sat. press., P_{sat} kPa	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
0.01	0.6113	0.001000	206.14	0.0	2375.3	2375.3	0.01	2501.3	2501.4	0.000	9.1562	9.1562
5	0.8721	0.001000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008
15	1.7051	0.001001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	0.2245	8.5569	8.7814
20	2.339	0.001002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	0.2966	8.3706	8.6672
25	3.169	0.001003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	0.3674	8.1905	8.5580
30	4.246	0.001004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	0.4369	8.0164	8.4533
35	5.628	0.001006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	0.5053	7.8478	8.3531
40	7.384	0.001008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	0.5725	7.6845	8.2570
45	9.593	0.001010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	0.6387	7.5261	8.1648
50	12.349	0.001012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	0.7038	7.3725	8.0763
55	15.758	0.001015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	0.7679	7.2234	7.9913
60	19.940	0.001017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	0.8312	7.0784	7.9096
65	25.03	0.001020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	0.8935	6.9375	7.8310
70	31.19	0.001023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	0.9549	6.8004	7.7553
75	38.58	0.001026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001040	1.982	397.88	2102.7	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159
	Sat. press., MPa											
100	0.10135	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
105	0.12082	0.001048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8	1.3630	5.9328	7.2958
110	0.14327	0.001052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5	1.4185	5.8202	7.2387
115	0.16906	0.001056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0	1.4734	5.7100	7.1833
120	0.19853	0.001060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3	1.5276	5.6020	7.1296
125	0.2321	0.001065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
130	0.2701	0.001070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5	1.6344	5.3925	7.0269
135	0.3130	0.001075	0.5822	567.35	1977.7	2545.0	567.69	2159.6	2727.3	1.6870	5.2907	6.9777
140	0.3613	0.001080	0.5089	588.74	1961.3	2550.0	589.13	2144.7	2733.9	1.7391	5.1908	6.9299
145	0.4154	0.001085	0.4463	610.18	1944.7	2554.9	610.63	2129.6	2740.3	1.7907	5.0926	6.8833
150	0.4758	0.001091	0.3928	631.68	1927.9	2559.5	632.20	2114.3	2746.5	1.8418	4.9960	6.8379
155	0.5431	0.001096	0.3468	653.24	1910.8	2564.1	653.84	2098.6	2752.4	1.8925	4.9010	6.7935
160	0.6178	0.001102	0.3071	674.87	1893.5	2568.4	675.55	2082.6	2758.1	1.9427	4.8075	6.7502
165	0.7005	0.001108	0.2727	696.56	1876.0	2572.5	697.34	2066.2	2763.5	1.9925	4.7153	6.7078
170	0.7917	0.001114	0.2428	718.33	1858.1	2576.5	719.21	2049.5	2768.7	2.0419	4.6244	6.6663
175	0.8920	0.001121	0.2168	740.17	1840.0	2580.2	741.17	2032.4	2773.6	2.0909	4.5347	6.6256
180	1.0021	0.001127	0.19405	762.09	1821.6	2583.7	763.22	2015.0	2778.2	2.1396	4.4461	6.5857
185	1.1227	0.001134	0.17409	784.10	1802.9	2587.0	785.37	1997.1	2782.4	2.1879	4.3586	6.5465
190	1.2544	0.001141	0.15654	806.19	1783.8	2590.0	807.62	1978.8	2786.4	2.2359	4.2720	6.5079
195	1.3978	0.001149	0.14105	828.37	1764.4	2592.8	829.98	1960.0	2790.0	2.2835	4.1863	6.4698