NATIONAL EXAMINATIONS – May 2016

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 Casio or Sharp 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. The **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 Water is the working fluid in a vapor power cycle with reheat. Superheated vapor enters the first turbine stage at 8 MPa, 480°C and expands to 0.7 MPa. Then, it is reheated to 480°C before entering the second turbine stage, where it expands to the condenser pressure of 8 kPa. The mass flow rate of steam entering the first turbine stage is 2.63×10^5 kg/h. Each turbine stage operates with an isentropic efficiency of 88%. The pump operates with an isentropic efficiency of 80%. Sketch the cycle on a T-s diagram with respect to saturation lines. Determine

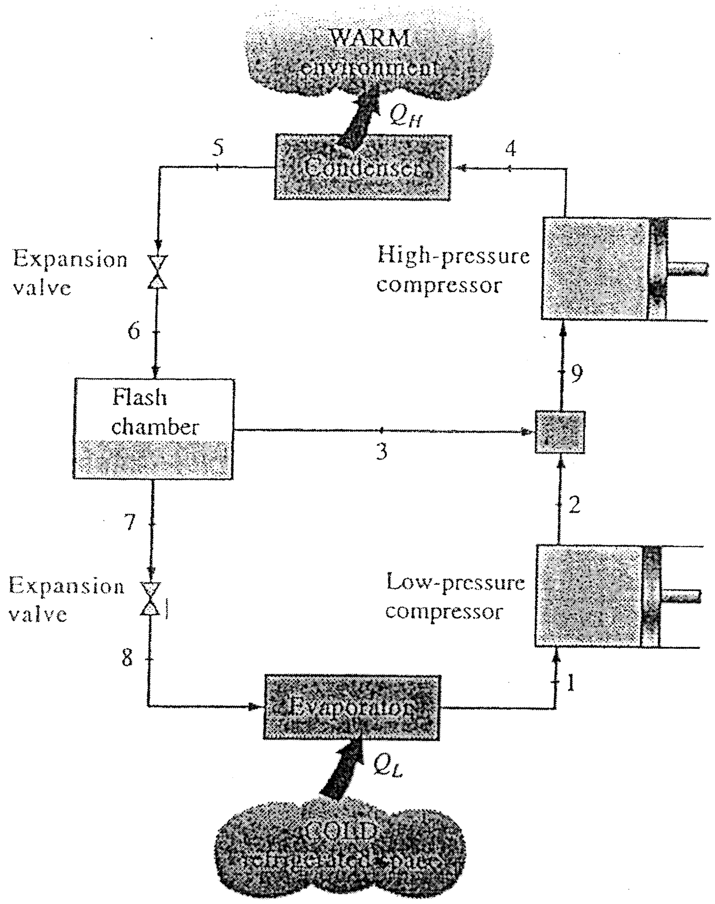
(a) the rate of the heat input to the working fluid, in kW,
(b) the rate of the heat rejected from the working fluid, in kW
(c) the net power output, in kW, and
(d) the thermal efficiency.

2. Consider a regenerative gas turbine with a two-stage air compressor that operates at steady state, compressing 10 m^3/min of air from 100 kPa and 300 K to 1 MPa. An intercooler between the two stages cools the air to 300 K at a constant pressure of 300 kPa. Each compressor stage has an isentropic efficiency of 85%. The turbine inlet temperature is 1300 K and the turbine has an isentropic efficiency of 87%. The regenerator effectiveness is 80%. Show the cycle on a T-s diagram. Accounting for the variation of specific heats with temperature, calculate

(a) the power required to run the compressor in kW,
(b) the thermal efficiency,
(c) the rate of heat addition in kW, and
(d) the net power developed in kW.

3. A two-state compression refrigeration system as shown in the figure operates with R-134a between the pressure limits of 1 and 0.14 MPa. The refrigerant leaves the condenser as saturated liquid and is throttled to a flash chamber operating at 0.5 MPa. The refrigerant leaving the low-pressure compressor at 0.5 MPa is mixed with the saturated vapor from the flash chamber and the mixture is then compressed to the condenser pressure by the high-pressure compressor, and the liquid is throttled to the evaporator pressure. The mass flow rate of the refrigerant through the condenser is 0.25 kg/s. Assuming the refrigerant leaves the evaporator as saturated vapor and both compressors are isentropic,

(a) sketch the cycle on a T-s diagram with respect to saturation lines,
(b) determine the amount of heat removed from the refrigerated space, in kW,
(c) determine the power input to refrigeration system, in kW, and
(d) determine the coefficient of performance.



PART B. DO ONLY FOUR OF QUESTIONS 4, 5, 6, 7, 8 or 9
(Each question is worth **15 marks**)

4. An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The minimum and maximum temperatures in the cycle are 310 and 1600 K. Accounting for the variation of specific heats with temperature, determine

   (a) the amount of heat transferred to air during the heat addition process, in kJ/kg,
   (b) the net work output of the cycle, in kJ/kg, and
   (c) the thermal efficiency.

5. A mixture of 80% of N_2 and 20% of 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. Treat the mixture as an ideal gas. Determine the work input to the compressor per unit mass of the mixture.

6. One kilogram of moist air initially at a pressure of 1 atm has a dry bulb temperature of 20°C and a relative humidity of 60 percent and is contained in a closed rigid vessel. Determine the heat transfer to the moist air that is required to increase the dry bulb temperature to 50°C. Calculate the final pressure and final relative humidity of the mixture.

7. Steam at 1.0 MPa and 320°C with a mass flow rate of 10 kg/s enters an insulated turbine operating at steady state and exits at 20 kPa. If the work developed by the turbine is measured as 630 kJ/kg, determine

   (a) the isentropic efficiency of the turbine,
   (b) the exit temperature,
   (c) the quality at the exit if a two-phase liquid-vapor mixture exits, and
   (d) whether the process is a reversible process.

8. A piston-cylinder assembly contains a two-phase liquid-vapor mixture of H_2O initially at 500 kPa with a quality of 98%. Expansion occurs to a state where the pressure is 150 kPa. During the process, the pressure and specific volume are related by pv = constant. Determine

   (a) the work per unit mass, in kJ/kg, and
   (b) heat transfer per unit mass, in kJ/kg.

9. An insulated vessel is divided into two compartments connected by a valve. Initially, one compartment contains steam at 1.0 MPa, 500°C, and the other is evacuated. The valve is opened and the steam is allowed to fill the entire volume, achieving the final pressure of 0.1 MPa. Determine

   (a) the final temperature, in °C,
   (b) the percentage of the vessel volume initially occupied by the steam, and
   (c) the amount of entropy produced, in kJ/kgK.

APPENDIX – TABLES AND CHART

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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 m^3/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 · m^3/(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.