UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 4 Examination in Engineering: February 2020

Module Number: ME 4301 **Module Name: Applied Thermodynamics (N/C)**

[Three Hours]

[Answer **all questions**, each question carries **ten** marks]

All assumptions must be stated clearly. Sketches and diagrams are to be provided where required. Symbols stated herein denote standard parameters.

Q1 a) Discuss the basic considerations in the analysis of actual and ideal power cycles with Idealizations and Simplifications parameters.

[1.0 Mark]

b) Discuss the reasons for deviation of actual gas turbine cycles from idealized ones with suitable diagrams.

[2.0 Marks]

c) Discuss the need of followings for a gas turbine with suitable sketches and details.

i) Regenerator

ii) Intercooler and Re-heater

[2.0 Marks]

d) An ideal gas-turbine cycle with two stages of compression and two stages of expansion has an overall pressure ratio of 8. Air enters each stage of the compressor at 300 K and each stage of the turbine at 1300 K.

Determine

- the back work ratio
- the thermal efficiency of this gas-turbine cycle,

(If compressor inlets are state 1 and 3, turbine outlets are state 7 and 9 and other state numbers are in a sequential manner)

Assuming

i) No regenerators and

[2.0 Marks]

ii) An ideal regenerator with 100 percent effectiveness.

[3.0 Marks]

Q2 a) Draw the T-s diagram for water with seven phases and critical point values.

[1.0 Mark]

b) Discuss the reasons for the deviation of actual Vapor power cycles from idealized ones with suitable parameters ad diagrams.

[2.0 Marks]

c) Discuss the need of reheaters and regeneration process in a steam power plant with suitable details separately.

[2.0 Marks]

d) The Figure Q2) d) shows a systematic diagram of a combined gas–steam power plant. The topping cycle is a simple Brayton cycle that has a pressure ratio of 7. Air enters the compressor at 15 ^{0}C at a rate of 40 kg/s and the gas turbine at 950 ^{0}C. The bottoming cycle is a reheat Rankine cycle between the pressure limits of 6 MPa and 10 kPa. Steam is heated in a heat exchanger at a rate of 4.6 kg/s by the exhaust gases leaving the gas turbine, and the exhaust gases leave the heat exchanger at 200 ^{0}C. Steam leaves the high-pressure turbine at 1.0 MPa and is reheated to 400 ^{0}C in the heat exchanger before it expands in the low-pressure turbine.

i) Draw a clear T-s diagram of the given combined power plant with mentioning all given parameters.

[3.0 Marks]

ii) If you are going to find the net-work output of the plant step by step, what will be the equations needed to be used if all the enthalpy values (h_1 to h_{11}) are known? Mention the equations clearly with suitable state numbers.

[2.0 Marks]

Q3 a) Define and derive stagnation properties (enthalpy, pressure, density) of incompressible fluid.

[2.0 Marks]

b) Discuss the need of a diffuser before compressor.

[1.0 Mark]

c) Discuss the effect (with diagrams) on the fluid pressure and Mach number while changing the back pressure of a converging-diverging nozzle if you are given following relations with usual notations.

$$\frac{dA}{A} = \frac{dP}{\rho V^2}(1 - Ma^2)$$

$$\frac{dA}{A} = \frac{-dV}{V}(1 - Ma^2)$$

Clue: Pressure at the entrance is at stagnation and take P_o=P_e as the first relation.

[2.0 Marks]

d) Carbon dioxide flows steadily through a varying cross-sectional area duct such as a converging-diverging nozzle at a mass flow rate of 3.00 kg/s. The carbon dioxide enters the duct at a pressure of 1400 kPa and 200 °C with a low velocity, and it expands in the nozzle to an exit pressure of 200 kPa. The duct is designed so that the flow can be approximated as isentropic.

Determine the critical properties of the fluid (density, flow area, and temperature)

Given: c_p = 0.846 kJ/kg·K , k = 1.289 and gas constant of carbon dioxide is R = 0.1889 kJ/kg·K.

[5.0 Marks]

Q4 a) Discuss the pressure and velocity variation when the working fluid passes through the stator and rotor in main two types of turbines with the aid of suitable sketches.

[2.0 Marks]

b) Draw a systematic diagram for a pressure-velocity compounded impulse turbine and discuss briefly.

[3.0 Marks]

c) Draw a PV diagram for ideal Otto cycle and write down the equations with usual notations (assuming all the properties are given) which are need to calculate

i) net-work output of the engine

[2.0 Marks]

ii) mean effective pressure of the engine

[2.0 Marks]

iii) thermal efficiency of the engine

[1.0 Marks]

Q5 a) Discuss the need of studying on the fire triangle.

[1.0 Mark]

b) A chemical reaction during which a fuel is oxidized and a large quantity of energy is released is called combustion. The oxidizer most often used in combustion processes is air, for obvious reasons—it is free and readily available.
Discuss the need of studying on the composition of air for combustion.

[1.0 Marks]

c) Discuss the terms stoichiometric or theoretical air, excess air and deficiency of air with suitable examples.

[3.0 Marks]

c) Coal from Pennsylvania which has an ultimate analysis (by mass) as 84.36 percent C, 1.89 percent H_2, 4.40 percent O_2, 0.63 percent N_2, 0.89 percent S, and 7.83 percent ash (non-combustibles) is burned with theoretical amount of air. Disregarding the ash content, determine the mole fractions of the products and the apparent molar mass of the product gases.

Given: The molar masses of C, H_2, O_2, S, and air are 12, 2, 32, 32, and 29 kg/kmol, respectively

[5.0 Marks]

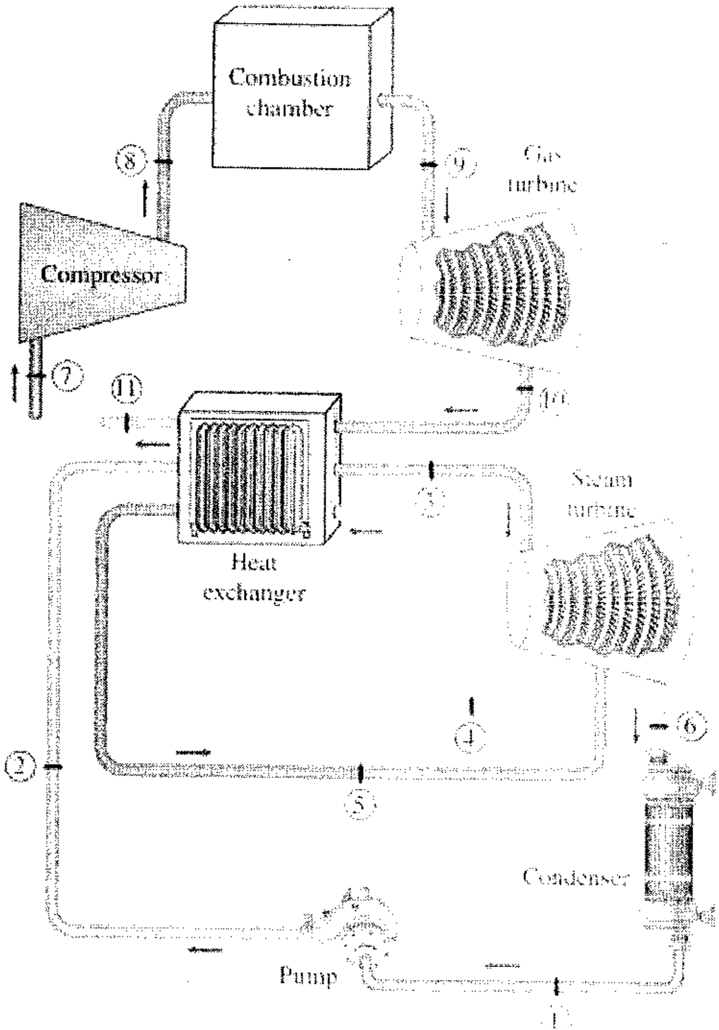

Figure Q2) d): A systematic diagram of a steam power plant with one open and three closed feed water heaters

TABLE A–17

Ideal-gas properties of air

T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K	T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K
200	199.97	0.3363	142.56	1707.0	1.29559	580	586.04	14.38	419.55	115.7	2.37348
210	209.97	0.3987	149.69	1512.0	1.34444	590	596.52	15.31	427.15	110.6	2.39140
220	219.97	0.4690	156.82	1346.0	1.39105	600	607.02	16.28	434.78	105.8	2.40902
230	230.02	0.5477	164.00	1205.0	1.43557	610	617.53	17.30	442.42	101.2	2.42644
240	240.02	0.6355	171.13	1084.0	1.47824	620	628.07	18.36	450.09	96.92	2.44356
250	250.05	0.7329	178.28	979.0	1.51917	630	638.63	19.84	457.78	92.84	2.46048
260	260.09	0.8405	185.45	887.8	1.55848	640	649.22	20.64	465.50	88.99	2.47716
270	270.11	0.9590	192.60	808.0	1.59634	650	659.84	21.86	473.25	85.34	2.49364
280	280.13	1.0889	199.75	738.0	1.63279	660	670.47	23.13	481.01	81.89	2.50985
285	285.14	1.1584	203.33	706.1	1.65055	670	681.14	24.46	488.81	78.61	2.52589
290	290.16	1.2311	206.91	676.1	1.66802	680	691.82	25.85	496.62	75.50	2.54175
295	295.17	1.3068	210.49	647.9	1.68515	690	702.52	27.29	504.45	72.56	2.55731
298	298.18	1.3543	212.64	631.9	1.69528	700	713.27	28.80	512.33	69.76	2.57277
300	300.19	1.3860	214.07	621.2	1.70203	710	724.04	30.38	520.23	67.07	2.58810
305	305.22	1.4686	217.67	596.0	1.71865	720	734.82	32.02	528.14	64.53	2.60319
310	310.24	1.5546	221.25	572.3	1.73498	730	745.62	33.72	536.07	62.13	2.61803
315	315.27	1.6442	224.85	549.8	1.75106	740	756.44	35.50	544.02	59.82	2.63280
320	320.29	1.7375	228.42	528.6	1.76690	750	767.29	37.35	551.99	57.63	2.64737
325	325.31	1.8345	232.02	508.4	1.78249	760	778.18	39.27	560.01	55.54	2.66176
330	330.34	1.9352	235.61	489.4	1.79783	780	800.03	43.35	576.12	51.64	2.69013
340	340.42	2.149	242.82	454.1	1.82790	800	821.95	47.75	592.30	48.08	2.71787
350	350.49	2.379	250.02	422.2	1.85708	820	843.98	52.59	608.59	44.84	2.74504
360	360.58	2.626	257.24	393.4	1.88543	840	866.08	57.60	624.95	41.85	2.77170
370	370.67	2.892	264.46	367.2	1.91313	860	888.27	63.09	641.40	39.12	2.79783
380	380.77	3.176	271.69	343.4	1.94001	880	910.56	68.98	657.95	36.61	2.82344
390	390.88	3.481	278.93	321.5	1.96633	900	932.93	75.29	674.58	34.31	2.84856
400	400.98	3.806	286.16	301.6	1.99194	920	955.38	82.05	691.28	32.18	2.87324
410	411.12	4.153	293.43	283.3	2.01699	940	977.92	89.28	708.08	30.22	2.89748
420	421.26	4.522	300.69	266.6	2.04142	960	1000.55	97.00	725.02	28.40	2.92128
430	431.43	4.915	307.99	251.1	2.06533	980	1023.25	105.2	741.98	26.73	2.94468
440	441.61	5.332	315.30	236.8	2.08870	1000	1046.04	114.0	758.94	25.17	2.96770
450	451.80	5.775	322.62	223.6	2.11161	1020	1068.89	123.4	776.10	23.72	2.99034
460	462.02	6.245	329.97	211.4	2.13407	1040	1091.85	133.3	793.36	23.29	3.01260
470	472.24	6.742	337.32	200.1	2.15604	1060	1114.86	143.9	810.62	21.14	3.03449
480	482.49	7.268	344.70	189.5	2.17760	1080	1137.89	155.2	827.88	19.98	3.05608
490	492.74	7.824	352.08	179.7	2.19876	1100	1161.07	167.1	845.33	18.896	3.07732
500	503.02	8.411	359.49	170.6	2.21952	1120	1184.28	179.7	862.79	17.886	3.09825
510	513.32	9.031	366.92	162.1	2.23993	1140	1207.57	193.1	880.35	16.946	3.11883
520	523.63	9.684	374.36	154.1	2.25997	1160	1230.92	207.2	897.91	16.064	3.13916
530	533.98	10.37	381.84	146.7	2.27967	1180	1254.34	222.2	915.57	15.241	3.15916
540	544.35	11.10	389.34	139.7	2.29906	1200	1277.79	238.0	933.33	14.470	3.17888
550	555.74	11.86	396.86	133.1	2.31809	1220	1301.31	254.7	951.09	13.747	3.19834
560	565.17	12.66	404.42	127.0	2.33685	1240	1324.93	272.3	968.95	13.069	3.21751
570	575.59	13.50	411.97	121.2	2.35531						

TABLE A–17

Ideal-gas properties of air (*Concluded*)

T K	*h* kJ/kg	P_r	*u* kJ/kg	v_r	$s°$ kJ/kg · K	*T* K	*h* kJ/kg	P_r	*u* kJ/kg	v_r	$s°$ kJ/kg · K
1260	1348.55	290.8	986.90	12.435	3.23638	1600	1757.57	791.2	1298.30	5.804	3.52364
1280	1372.24	310.4	1004.76	11.835	3.25510	1620	1782.00	834.1	1316.96	5.574	3.53879
1300	1395.97	330.9	1022.82	11.275	3.27345	1640	1806.46	878.9	1335.72	5.355	3.55381
1320	1419.76	352.5	1040.88	10.747	3.29160	1660	1830.96	925.6	1354.48	5.147	3.56867
1340	1443.60	375.3	1058.94	10.247	3.30959	1680	1855.50	974.2	1373.24	4.949	3.58335
1360	1467.49	399.1	1077.10	9.780	3.32724	1700	1880.1	1025	1392.7	4.761	3.5979
1380	1491.44	424.2	1095.26	9.337	3.34474	1750	1941.6	1161	1439.8	4.328	3.6336
1400	1515.42	450.5	1113.52	8.919	3.36200	1800	2003.3	1310	1487.2	3.994	3.6684
1420	1539.44	478.0	1131.77	8.526	3.37901	1850	2065.3	1475	1534.9	3.601	3.7023
1440	1563.51	506.9	1150.13	8.153	3.39586	1900	2127.4	1655	1582.6	3.295	3.7354
1460	1587.63	537.1	1168.49	7.801	3.41247	1950	2189.7	1852	1630.6	3.022	3.7677
1480	1611.79	568.8	1186.95	7.468	3.42892	2000	2252.1	2068	1678.7	2.776	3.7994
1500	1635.97	601.9	1205.41	7.152	3.44516	2050	2314.6	2303	1726.8	2.555	3.8303
1520	1660.23	636.5	1223.87	6.854	3.46120	2100	2377.7	2559	1775.3	2.356	3.8605
1540	1684.51	672.8	1242.43	6.569	3.47712	2150	2440.3	2837	1823.8	2.175	3.8901
1560	1708.82	710.5	1260.99	6.301	3.49276	2200	2503.2	3138	1872.4	2.012	3.9191
1580	1733.17	750.0	1279.65	6.046	3.50829	2250	2566.4	3464	1921.3	1.864	3.9474

Note: The properties P_r (relative pressure) and v_r (relative specific volume) are dimensionless quantities used in the analysis of isentropic processes, and should not be confused with the properties pressure and specific volume.

Source: Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 785–86, table A–5. Originally published in J. H. Keenan and J. Kaye, *Gas Tables* (New York: John Wiley & Sons, 1948).