APPLIED THERMODYNAMICS (SKMM 2423)
TEST 1 (Sem 1 2016/2017)
15/10/2016
(2:00 pm – 3:30 pm)

ANSWER ALL QUESTIONS

Question 1 *(10 marks)*

Steam is supplied to a two-stage turbine at 40 bar and 350° C. It expands in the first turbine until it is just dry saturated, then it is re-heated to 350° C and expanded through the second-stage turbine. The condenser pressure is 0.030 bar. Assume ideal processes and neglecting the feed-pump term (refer to Table 1: Property Table for water).

a) Sketch and label the schematic diagram of the steam plant.
b) Sketch and label the cycle on a temperature-entropy (*T-s)* diagram.
c) Calculate the work output per kilogram of steam for the plant, [kJ/kg].
d) Calculate the heat supplied per kilogram of steam for the plant, [kJ/kg].
e) Determine the specific steam consumption, [kg/kWh].
f) Calculate the cycle efficiency, [%].

Question 2 *(10 marks)*

In a marine gas turbine unit a high pressure (HP) stage turbine drives the compressor, and a low pressure (LP) stage turbine drives the propeller through suitable gearing. The overall pressure ratio is 4/1, the mass flow rate is 60 kg/s, the maximum temperature is 650° C, and the air intake conditions are 1.01 bar and 25° C. The isentropic efficiencies of the compressor, HP turbine, and LP turbine, are 0.8, 0.83, and 0.85 respectively. The mechanical efficiency of both shafts is 98%. Neglect kinetic energy changes, and the pressure loss in combustion. (For air: take c_p = 1.005 kJ/kgK and γ = 1.4. For combustion and expansion process: c_p = 1.15 kJ/kgK and γ = 1.333).

a) Sketch and label the schematic diagram of the plant.
b) Sketch and label the process on a temperature-entropy (*T-s)* diagram.
c) Calculate the pressure between turbine stages, [bar].
d) Determine the cycle efficiency, [%].
e) Calculate the shaft power, [kW].

Table 1: Property Table for water (for Question 1 only)

Superheated water (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 1.00 MPa (179.88°C)				*P* = 1.20 MPa (187.96°C)				*P* = 1.40 MPa (195.04°C)			
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
500	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047

Superheated water (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 4.0 MPa (250.35°C)				*P* = 4.5 MPa (257.44°C)				*P* = 5.0 MPa (263.94°C)			
Sat.	0.04978	2601.7	2800.8	6.0696	0.04406	2599.7	2798.0	6.0198	0.03945	2597.0	2794.2	5.9737
275	0.05461	2668.9	2887.3	6.2312	0.04733	2651.4	2864.4	6.1429	0.04144	2632.3	2839.5	6.0571
300	0.05887	2726.2	2961.7	6.3639	0.05138	2713.0	2944.2	6.2854	0.04535	2699.0	2925.7	6.2111
350	0.06647	2827.4	3093.3	6.5843	0.05842	2818.6	3081.5	6.5153	0.05197	2809.5	3069.3	6.4516
400	0.07343	2920.8	3214.5	6.7714	0.06477	2914.2	3205.7	6.7071	0.05784	2907.5	3196.7	6.6483
450	0.08004	3011.0	3331.2	6.9386	0.07076	3005.8	3324.2	6.8770	0.06332	3000.6	3317.2	6.8210

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg·K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734

Saturated water—Pressure table (*Concluded*)

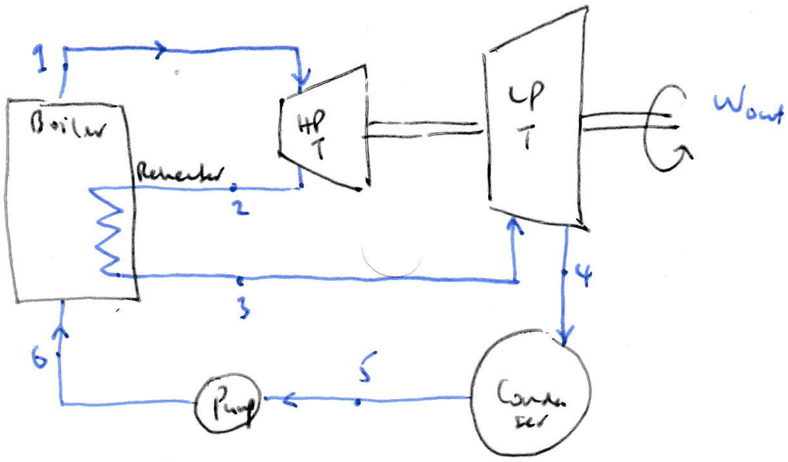
Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg·K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3	2.0457	4.6160	6.6616
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	2.0705	4.5705	6.6409
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	2.0941	4.5273	6.6213
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	2.1166	4.4862	6.6027
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	2.1381	4.4470	6.5850
1100	184.06	0.001133	0.17745	779.78	1805.7	2585.5	781.03	1999.6	2780.7	2.1785	4.3735	6.5520

SKMM 2423
Test 1

Question 1

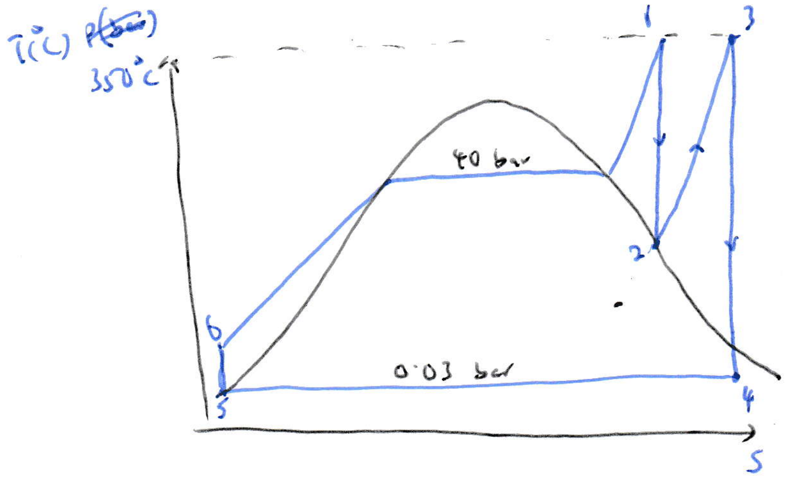
(a)

(1)



(b)

(1)



(c)

$$W_{out} = W_{12} + W_{34}$$
$$= (h_1 - h_2) + (h_3 - h_4)$$

from Table ⇒ at 40 bar & 350°C ;

$h_1 = 3093.3 \ kJ/kg$

$S_2 = S_1 = 6.584 \ kJ/kgK$

from Table ; at $S_2 = 6.584 \ kJ/kgK$

$P_2 = 10$ bar

$h_2 = h_g = 2777.1 \ kJ/kg$.

from Table ; at 10 bar & 350°C

$h_3 = 3158.2 \ kJ/kg$.

$S_4 = S_3 = 7.303 \ kJ/kgK$

from Table ; at 0·03 bar

$S_f = 0.3543 \ kJ/kg$.

$S_{fg} = 8.222 \ kJ/kgK$

$h_f = 100.98 \ kJ/kg$

$h_{fg} = 2444 \ kJ/kg$.

$s_4 = s_3 = s_f + x_4 s_{fg}$.

$7303 = 0.3543 + x_4 (8.222)$

$x_4 = 0.845$

$h_4 = h_f + x_4 h_{fg}$

$= 100.98 + (0.845)(2444)$

$= 2166$ kJ/kg.

$\therefore W_{out} = (h_1 - h_2) + (h_3 - h_4)$

$= (3093.3 - 2777.1) + (3158.2 - 2166)$

$= 1308.4$ kJ/kg #. — (2)

(d) $Q_{in} = Q_{61} + Q_{23}$

$= (h_1 - h_6) + (h_3 - h_2)$

$= (3093.3 - 100.98) + (3158.2 - 2777.1)$

$= 3374$ kJ/kg #. — (2)

$h_6 = h_5 = h_{f @ 0.07 bar}$

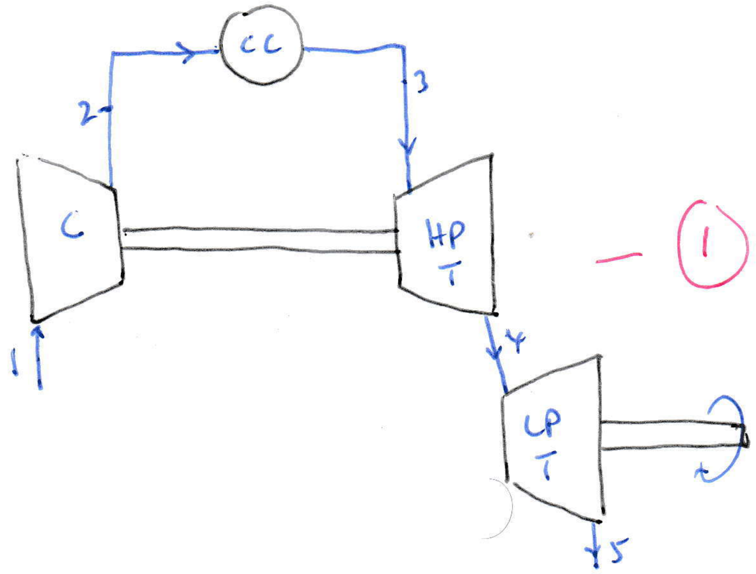
$= 100.98$ kJ/kg.

(e) $S.S.C = \frac{3600}{W_{out}} = \frac{3600}{1308.4} = 2.75$ kg/kWh #. — (2)

(f) $\eta = \frac{W_{out}}{Q_{in}} = \frac{1308.4}{3374} = 38.8\%$ #. — (2)

Question 2

(a)



— 1

Given;

$r_p = 4$

$\dot{m} = 60$ kg/s

$T_3 = 650°C = 923$ K

$P_1 = 1.01$ bar

$T_1 = 25°C = 298$ K

$\eta_{is,c} = 0.8$

$\eta_{is,HP} = 0.83$

$\eta_{is,LP} = 0.85$

$\eta_m = 0.98$

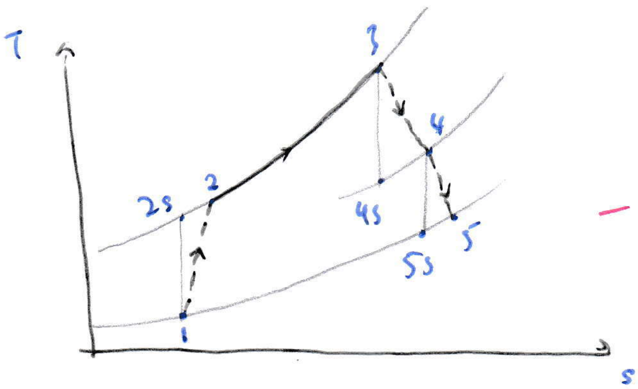
$C_{p,air} = 1.0055$ kJ/kgK

$\gamma = 1.4$

$C_{p,g} = 1.15$ kJ/kgK

$\gamma = 1.333$

(b)



— 1

(c)

isentropic process;

$$T_{2s} = T_1 \, r_p^{\frac{\gamma-1}{\gamma}}$$

$$= 298 (4)^{0.4/1.4}$$

$$= 442.8 \text{ K}$$

$$\eta_{is,c} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$0.8 = \frac{442.8 - 298}{T_2 - 298}$$

$$T_2 = 479 \text{ K}$$ — 1

$$W_{c,in} = C_{p,a}(T_2 - T_1)$$

$$= 1.055 (479 - 298)$$

$$= 181.91 \text{ kJ/kg}$$ — 1

$$W_{HPT,o} = C_{p,g}(T_3 - T_4) = \frac{W_{c,in}}{0.98}$$

$$1.15 (T_3 - T_4) = \frac{181.91}{0.98}$$

$$T_3 - T_4 = 161.4 \text{ K}$$

$$\therefore T_4 = -161.4 + 923$$

$$T_4 = 761.6 \text{ K}$$

(x)

$$\eta_{is,HP} = \frac{T_3 - T_4}{T_3 - T_{4s}}$$

$$0.83 = \frac{923 - 761.6}{923 - T_{4s}}$$

$T_{4s} = 728.5\ K$ — (1)

$$\frac{T_{4s}}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{728.5}{923} = \left(\frac{P_4}{4.04}\right)^{\frac{0.333}{1.333}}$$

$P_4 = 1.568\ bar$ # — (1)

$$\frac{P_2}{P_1} = \frac{P_3}{P_5} = \frac{P_3}{P_1} = r_p.$$

$$\frac{P_3}{1.01} = 4$$

$P_3 = 4.04\ bar.$

(d) isentropic process ;

$$\frac{T_{5s}}{T_4} = \left(\frac{P_5}{P_4}\right)^{\gamma-1/\gamma}$$

$$\frac{T_{5s}}{761.6} = \left(\frac{1.01}{1.568}\right)^{0.33/1.33}$$

$T_{5s} = 682.3\ K$

$$\eta_{is,LPT} = \frac{T_4 - T_5}{T_4 - T_{5s}}$$

$$0.85 = \frac{761.6 - T_5}{761.6 - 682.3}$$

$T_5 = 694.2\ K.$

$$\frac{W_{net}}{\eta_m} = c_{p,g}(T_4 - T_5)$$

$W_{net} = 1.15(761.6 - 694.2)0.98$

$= 76\ kJ/kg.$ — (1)

$Q_{in} = c_{pg}(T_3 - T_2)$

$= 1.15(923 - 479)$

$= 510.6\ kJ/kg.$ — (1)

$$\therefore \eta = \frac{W_{net}}{Q_{in}} = \frac{76}{510.6} = 14.9\%$$ # — (1)

(e) Net power $= W_{net} \times \dot{m}$

$= 76 \times 60$

$= 4560\ kW$ # — (1)