CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 13 OCTOBER 2014

1315 - 1615 hrs

Examination paper inserts:

Datasheet Q6 - Property table for CO_2

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.

2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A perfect gas is heated at constant pressure in a cylinder and then expands reversibly according to the law $pV^{1.32} = C$.

   The initial pressure and temperature are 10 bar 527°C respectively.

   The final pressure is 1.0 bar and the final volume is twenty times the initial volume.

   (a) Sketch the p-V and T-s diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the temperature after heating; (2)

   (ii) the final temperature; (2)

   (iii) the net heat transfer per kg of gas; (6)

   (iv) the net change in specific entropy during the constant pressure process. (2)

   Note: For the gas $\gamma = 1.67$, $c_p = 5.179$ *kJ/kgK* $R = 2.078$ *kJ/kgK*

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2. The layout of a gas turbine plant is shown in Fig Q2. The plant operates between pressures of 0.98 bar and 7.01 bar. All the work produced by the HP turbine drives the compressor.

The LP turbine drives the load. Air enters the compressor at 26°C and the combustion gas enters the HP turbine at 985°C.

The isentropic efficiency of the compressor is 0.84 and that of each turbine is 0.86.

(a) Sketch the cycle on a T-s diagram. (4)

(b) Calculate EACH of the following:

(i) the temperature at the HP turbine exhaust; (4)

(ii) the pressure at the HP turbine exhaust; (4)

(iii) the net work output per kg of air. (4)

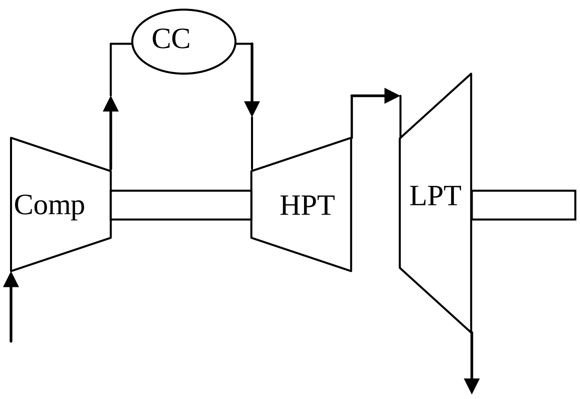

Fig Q2

Note: For all processes $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*

3. A fuel of mass analysis 84% Carbon and 16% Hydrogen is completely burned in air. The dry flue gas analysis shows that they contain 84% Nitrogen by volume.

(a) Use molar volumes to formulate the complete combustion equation in kmol/kg of fuel. (10)

(b) Calculate EACH of the following:

(i) the percentage excess air by volume; (3)

(ii) the air fuel ratio by mass. (3)

Note: Relative atomic masses H=1, C=12, N=14, O=16
Air contains 21% oxygen by volume

4. The volume of the shell of a steam condenser is 7.8 m^3. It contains 0.4 kg of wet steam and also a certain mass of air. The temperature is 34.6°C and the total pressure is 0.065 bar.

After a time, 38.9 grams of steam has condensed and an additional 0.04 kg of air has leaked in.

Determine EACH of the following:

(a) the initial mass of air present; (3)

(b) the initial mass of dry saturated vapour present; (2)

(c) the initial mass of saturated liquid present; (2)

(d) the final temperature; (5)

(e) the final total pressure. (4)

Note: For air R = 0.287 kJ/kgK

5. The blades in a certain stage in a 50% reaction turbine produce 200 kW when the steam is dry saturated at a pressure of 2.5 bar. The speed of rotation is 4500 rev/min.

The mean blade ring diameter is 800 mm and the blade height is 50 mm.

The absolute velocity of the steam at exit from the stage is in an axial direction.

(a) Sketch the velocity vector diagram identifying all the velocities. (3)

(b) Determine EACH of the following:

(i) the absolute velocity of the steam at exit; (7)

(ii) the fixed and moving blade angles; (2)

(iii) the absolute velocity of the steam at inlet; (2)

(iv) the blade to steam speed ratio. (2)

6. A vapour compression refrigeration cycle using CO_2 operates between pressures of 25.0095 bar and 68.9182 bar. It produces 6 tonnes per day of ice at -8°C, from fresh water at 20°C.
The refrigerant enters the compressor as a dry saturated vapour and leaves at a temperature of 78°C, it is then condensed and enters the expansion valve as saturated liquid.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Using Datasheet Q6, determine EACH of the following:

(i) the swept volume of the compressor if the volumetric efficiency is 88%; (8)

(ii) the compressor power; (2)

(iii) the coefficient of performance of the plant. (2)

Note: For Ice: specific heat capacity 2.1 kJ/kgK, latent heat 335 kJ/kg
For water: specific heat capacity 4.2 kJ/kgK

7. In a counter flow oil cooler, the oil flows with a velocity of 1.2 m/s through a single pass of 35 tubes. Each tube has a bore diameter of 15 mm and wall thickness of 1.6 mm.

The oil enters at a temperature of 80°C and leaves at a temperature of 30°C.

The fresh water coolant enters at a rate of 7 kg/s and a temperature of 24°C.

The overall heat transfer coefficient is 2000 W/m^2K, referenced to the tube outer surface area.

Calculate EACH of the following:

(a) the total mass flow rate of oil; (2)

(b) the outlet temperature of the water; (3)

(c) the logarithmic mean temperature difference; (5)

(d) the length of each tube. (6)

Note: For water: specific heat capacity 4.2 kJ/kgK
For oil: specific heat capacity 2.0 kJ/kgK, density 860 kg/m^3

8. A single stage, single acting reciprocating air compressor is used to charge a large air receiver.

The bore has a diameter of 750 mm and the stroke has length of 900 mm. The clearance volume is 9.5% of the swept volume and the mechanical efficiency is 86%.
The suction pressure and temperature are 1.0 bar and 25°C respectively.
The delivery pressure is 7.5 bar when running at a speed of 200 Rev/min.
The polytropic index for the compression and expansion process is 1.25.

(a) Sketch the process on a p-V diagram. (2)

(b) Calculate EACH of the following:

(i) the power input required; (7)

(ii) the maximum theoretical pressure that can be achieved from the given suction conditions; (3)

(c) Explain why the mass flow rate of air alters as the delivery pressure increases. (4)

Note: For air R = 0.287 kJ/kgK c_p *= 1.005 kJ/kgK*

9. A compartment of volume 6 m^3 contains Nitrogen at a pressure of 1.5 bar and is separated by a bulkhead from a second compartment of volume 3 m^3 containing Carbon Dioxide at a pressure of 0.85 bar. The temperature in each compartment is 22°C.

A door in the bulkhead is opened and the gasses mix adiabatically and completely.

Calculate EACH of the following:

(a) the final pressure; (7)

(b) the total change in entropy. (9)

Note: The universal gas constant R_o *= 8.3145 kJ/kmolK*
Relative atomic masses H=1, C=12, N=14, O=16

refrigerant: CO_2

saturation values							*superheat ($T - T_s$)* 50 K		*superheat ($T - T_s$)* 100 K	
T (°C)	p_s (bar)	v_g (m³/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/(kg K))	s_g (kJ/(kg K))	h (kJ/kg)	s (kJ/(kg K))	h (kJ/kg)	s (kJ/(kg K))
-50	6.8234	0.0558	-19.96	319.77	-0.0863	1.4362	365.1	1.620	409.9	1.770
-45	8.3184	0.0460	-10.03	321.23	-0.0428	1.4091	367.81	1.594	413.26	1.744
-40	10.0450	0.0383	0.00	322.42	0.0000	1.3829	370.35	1.569	416.53	1.720
-35	12.0242	0.0320	10.15	323.33	0.0423	1.3574	372.75	1.546	419.70	1.696
-30	14.2776	0.0270	20.43	323.92	0.0842	1.3323	375.00	1.524	422.77	1.674
-28	15.2607	0.0252	24.60	324.06	0.1009	1.3224	375.85	1.515	423.97	1.666
-26	16.2926	0.0236	28.78	324.14	0.1175	1.3125	376.68	1.507	425.15	1.657
-24	17.3749	0.0220	33.00	324.15	0.1341	1.3026	377.48	1.498	426.31	1.649
-22	18.5089	0.0206	37.26	324.11	0.1506	1.2928	378.25	1.490	427.45	1.641
-20	19.6963	0.0193	41.55	323.99	0.1672	1.2829	378.99	1.482	428.58	1.633
-18	20.9384	0.0181	45.87	323.80	0.1837	1.2730	379.70	1.474	429.68	1.626
-16	22.2370	0.0170	50.24	323.53	0.2003	1.2631	380.39	1.466	430.77	1.618
-14	23.5935	0.0159	54.65	323.19	0.2169	1.2531	381.04	1.458	431.83	1.610
-12	25.0095	0.0150	59.11	322.76	0.2334	1.2430	381.66	1.450	432.88	1.603
-10	26.4868	0.0140	63.62	322.23	0.2501	1.2328	382.25	1.443	433.90	1.596
-8	28.0269	0.0132	68.18	321.61	0.2668	1.2226	382.81	1.435	434.91	1.589
-6	29.6316	0.0124	72.81	320.89	0.2835	1.2121	383.34	1.428	435.89	1.582
-4	31.3027	0.0116	77.50	320.05	0.3003	1.2015	383.83	1.420	436.85	1.575
-2	33.0420	0.0109	82.26	319.09	0.3173	1.1907	384.29	1.413	437.79	1.568
0	34.8514	0.0102	87.10	317.99	0.3344	1.1797	384.71	1.405	438.71	1.561
2	36.7329	0.0096	92.02	316.75	0.3516	1.1683	385.10	1.398	439.61	1.554
4	38.6884	0.0090	97.05	315.35	0.3690	1.1567	385.45	1.391	440.49	1.548
6	40.7202	0.0084	102.18	313.77	0.3866	1.1446	385.77	1.384	441.34	1.541
8	42.8306	0.0079	107.43	311.99	0.4045	1.1321	386.05	1.377	442.17	1.535
10	45.0218	0.0074	112.83	309.98	0.4228	1.1190	386.29	1.369	442.97	1.528
12	47.2966	0.0069	118.38	307.72	0.4414	1.1053	386.49	1.362	443.76	1.522
14	49.6577	0.0064	124.13	305.15	0.4605	1.0909	386.65	1.355	444.51	1.516
16	52.1080	0.0060	130.11	302.22	0.4802	1.0754	386.77	1.348	445.25	1.509
18	54.6511	0.0056	136.36	298.86	0.5006	1.0588	386.85	1.341	445.95	1.503
20	57.2905	0.0051	142.97	294.96	0.5221	1.0406	386.88	1.334	446.64	1.497
22	60.0308	0.0047	150.02	290.36	0.5449	1.0203	386.87	1.327	447.29	1.491
24	62.8773	0.0043	157.71	284.80	0.5695	0.9972	386.81	1.320	447.91	1.485
26	65.8368	0.0039	166.36	277.80	0.5971	0.9697	386.70	1.313	448.51	1.478
28	68.9182	0.0035	176.72	268.30	0.6301	0.9342	386.53	1.305	449.07	1.472
30	72.1369	0.0029	191.65	252.23	0.6778	0.8776	386.30	1.298	449.58	1.466
30.98	73.7730	0.0021	219.34	219.34	0.7680	0.7680	386.15	1.294	449.82	1.463

based on data from NIST: ***www.nist.gov***