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, 15 OCTOBER 2012

1315 - 1615 hrs

Examination paper inserts:

Datasheet Q6 – Property data 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. Carbon dioxide, initially at a pressure of 5 bar and a temperature of 300°C, is heated at constant volume in a cylinder to a temperature of 600°C. It then expands reversibly according to the law $pV^{1.35}$ = constant until the pressure has returned to its original value.

   (a) Sketch the processes on p-v and T-s diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the final temperature; (3)

   (ii) the magnitude and direction of the total heat transfer per kg; (6)

   (iii) the total change in specific entropy. (3)

   Note: For CO_2, $R = 0.189$ kJ/kg K and $\gamma = 1.22$

2. The layout of a gas turbine plant is illustrated in Fig Q2. The plant operates between pressures of 1.00 bar and 8.00 bar. The HP turbine drives the compressor, and the LP turbine drives the load. Air enters the compressor at temperature of 18°C. Combustion gases enter the HP turbine at 997°C. The isentropic efficiency of the compressor is 0.80, and that of each turbine is 0.88. For ALL processes, $\gamma = 1.4$ and $c_P = 1.005$ kJ/kg K.

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

   (b) Calculate EACH of the following:

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

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

   (iii) the thermal efficiency. (4)

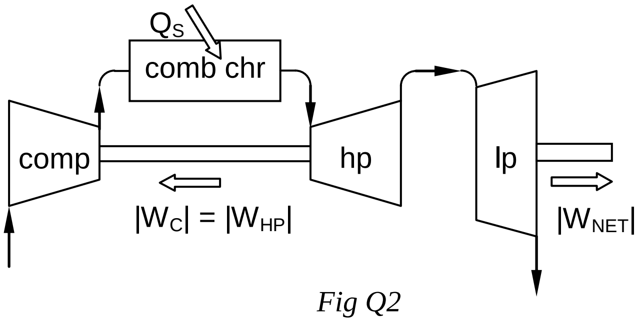

Fig Q2

[OVER

3. A fuel of mass analysis 80% carbon and 16% hydrogen (remainder non-combustible) is completely burned in air. Nitrogen forms 85% of the total dry products by volume.

Calculate EACH of the following:

(a) the air/fuel ratio by mass; (12)

(b) the percentage excess air. (4)

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

4. (a) An ideal steam plant operates on the Rankine cycle. The maximum and minimum pressures are respectively 40 bar and 0.08 bar. The steam is dry and saturated at the beginning of expansion, and there is no undercooling of the condensate. The work required to drive the feed pump may be disregarded.

Determine EACH of the following:

(i) the specific work output; (5)

(ii) the thermal efficiency. (2)

(b) An ideal steam plant with the same pressure limits as the plant in Q 4(a) operates on the Carnot cycle. The steam is dry and saturated at the beginning of expansion and saturated liquid at the end of compression.

Determine EACH of the following:

(i) the thermal efficiency; (2)

(ii) the net specific work output. (3)

(c) Give TWO reasons why practical steam plant cycles are designed to approximate to the Rankine rather than the Carnot cycle. (4)

5. In a stage of a 50% reaction turbine the steam is dry and saturated at a pressure of 3.0 bar. The mean blade diameter is 800 mm, the blade height is 50 mm and the speed of rotation is 4500 rev/min. The absolute velocity of the steam at exit from the stage is in an axial direction. The blade outlet angle is 25°.

(a) Sketch the combined velocity diagram, showing all relevant velocities and angles. (6)

(b) Determine EACH of the following:

(i) the blade power; (6)

(ii) the diagram efficiency. (4)

6. Data for CO_2 are given on Datasheet Q6. In a vapour compression cycle using CO_2 the evaporating temperature is -16°C and the condensing temperature is 30°C. The refrigerant enters the compressor at a temperature of -6°C and leaves at a temperature of 90°C. It leaves the condenser as saturated liquid. The density of the CO_2 at compressor inlet is 131.2 kg/m^3 and the volumetric efficiency of the compressor is 85%. The compressor is a single cylinder, single acting machine and has a swept volume of 200×10^{-6} m^3.

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

(b) Determine the coefficient of performance of the cycle. (7)

(c) Determine the speed of rotation of the compressor when the cooling load is 30 kW. (5)

7. Dry saturated steam enters the shell of a shell and tube condenser at a pressure of 0.091 bar and leaves as saturated liquid. The rate of heat transfer is 75 MW. The condenser has a total of 12000 tubes arranged in a single pass. Each tube has outside diameter 16 mm, wall thickness 1.2 mm and length 3.7 m. Cooling water enters the tubes at a temperature of 25°C and leaves at 31°C. The specific heat capacity of the cooling water is 4.2 kJ/(kg K) and its density is 1000 kg/m^3.

Determine EACH of the following:

(a) the mass flow rate of steam; (2)

(b) the mass flow rate of cooling water; (2)

(c) the logarithmic mean temperature difference; (4)

(d) the overall heat transfer coefficient, based on the tube outside surface area; (4)

(e) the mean flow velocity of the cooling water in the tubes. (4)

8. A single stage, single acting air compressor is used to charge a large air receiver. The bore diameter is 750 mm and the stroke length is 950 mm. The clearance volume is 0.03 m^3 and the index of compression and expansion is 1.31. The mechanical efficiency is 87%. Suction pressure and temperature are 1.00 bar and 25°C respectively. The compressor runs at 300 rev/min.

(a) Calculate, for a delivery pressure of 6 bar, EACH of the following:

(i) the power input required; (8)

(ii) the rate of jacket cooling. (3)

(b) Explain why the mass flow rate of air decreases as the delivery pressure rises. (2)

(c) Calculate the maximum theoretical delivery pressure which this compressor can achieve from the given suction conditions. (3)

Note: For air, R = 0.287 kJ/kg K and c_P *= 1.005 kJ/kg K.*

9. A 6 cylinder, 2-stroke compression ignition engine runs at 250 rev/min. The stroke volume of each cylinder is 0.12 m^3 and the indicated mean effective pressure is 7.2 bar. The shaft torque is 73.4 kNm. The fuel used has a calorific value of 42 MJ/kg and the brake specific fuel consumption is 0.225 kg/kWh. The air/fuel ratio by mass is 25/1. The cooling water enters at a temperature of 30°C and leaves at a temperature of 80°C. The specific heat capacity of the cooling water is 4.2 kJ/kg K, and it flows at a rate of 36 tonne/h.

Calculate EACH of the following:

(a) the mechanical efficiency; (5)

(b) the mass flow rate of exhaust gases; (3)

(c) the rate at which heat is lost to the exhaust gases (assuming that stray heat losses direct to the surroundings from hot engine parts may be disregarded). (8)

refrigerant: CO_2

saturation values							superheat ($T - T_s$)			
							50 K		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***