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 12 DECEMBER 2011

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. Ideal gas in a cylinder is cooled at constant pressure from a temperature of 1200°C to a temperature of 800°C, and then further cooled at constant volume from 800°C to 500°C. The change in specific entropy in the second process is -3.326 kJ/kg K. After being cooled, the gas is compressed isentropically to the initial pressure and a temperature of 577.3°C.

   (a) Sketch the processes on p-V and T-s diagrams. (6)

   (b) Determine EACH of the following:

   (i) the values of c_V, c_P, R and γ for the gas; (6)

   (ii) the change in specific entropy during the constant pressure process; (2)

   (iii) the work transfer per kg of gas during isentropic compression. (2)

2. In an air standard dual combustion cycle, the volume compression ratio is 26/1. The maximum and minimum temperatures are 2200 K and 305 K respectively. The maximum and minimum pressures are respectively 110 bar and 1.02 bar.

   (a) Sketch the cycle on p-V and T-S diagrams. (5)

   (b) Determine EACH of the following:

   (i) the thermal efficiency; (7)

   (ii) the mean effective pressure. (4)

   Note: For air, $\gamma = 1.4$ and $c_P = 1.005$ kJ/kg K.

3. The volumetric analysis of a gaseous fuel is: methane (CH_4) 50%; ethane (C_2H_6) 30%; ethylene (C_2H_4) 20%. The dry combustion products contain 3% CO and 6% O_2 by volume.

   (a) Formulate the full combustion equation per kmol of fuel. (12)

   (b) Determine the percentage excess air supplied. (4)

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

4. (a) A Carnot cycle uses saturated water and steam as the working fluid, and operates between pressures of 0.045 bar and 44 bar. At the beginning of heat supply, the state of the fluid is saturated liquid, and at the end of heat supply it is dry saturated vapour.

(i) Sketch the cycle on p-V and T-s diagrams. (4)

(ii) Determine the thermal efficiency of the cycle. (2)

(iii) Determine the specific work output of the cycle. (2)

(b) An ideal Rankine cycle using steam operates between the same pressures as the Carnot cycle in Q4(a). The steam is dry saturated at the beginning of expansion, and saturated liquid leaves the condenser.

(i) Sketch the cycle on the T-s diagram. (2)

(ii) Determine the specific work output of the cycle, allowing for feed pump work. (4)

(iii) Determine the thermal efficiency of the cycle. (2)

5. The drop in specific enthalpy as steam passes through the nozzles of a two-row velocity compounded impulse turbine stage is 500 kJ/kg. The nozzle angle is 18° and the mean blade velocity is 225 m/s. All the blades are symmetrical, and the blade friction coefficient is 0.9 for *all* blades.

(a) Sketch the velocity diagrams for each moving row, labelling all velocities and angles. (5)

(b) Determine EACH of the following:

(i) all the blade angles; (8)

(ii) the blade work per kg. (3)

6. A vapour compression cooling cycle using CO_2 operates between pressures of 20.9384 bar and 72.1369 bar. The refrigerant enters the compressor at a temperature of -13°C and leaves the condenser as a saturated liquid. The isentropic efficiency of the compressor is 85%.

(a) Sketch the cycle on p-h and T-s diagrams. (5)

(b) Using Datasheet Q6, determine the coefficient of performance of the cycle. (7)

(c) State TWO disadvantages and TWO advantages of CO_2 compared with other refrigerants. (4)

7. An LNG carrier has three spherical tanks each of diameter 44 m. They contain liquefied gas at a temperature of -163°C. The tanks are insulated with a 300 mm thickness of material of thermal conductivity 0.04 W/m K. The outside surface heat transfer coefficient is 12 W/m^2 K, and the temperature of the surrounding air is 30°C. The thermal resistances of the inside surface film and of the tank wall may be disregarded. The latent heat of evaporation of the gas is 510 kJ/kg.

Determine the mass of gas which boils off each day. (16)

8. At the beginning of compression in a single stage, single acting reciprocating air compressor, the air is at a pressure of 0.99 bar and a temperature of 15°C. The delivery valve opens at a pressure of 5.8 bar. The delivery temperature is 151°C. The bore diameter and stroke length are 0.28 m and 0.30 m respectively. The clearance volume is 5% of the swept volume and the compressor runs at 400 rev/min.

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

(b) Determine EACH of the following:

(i) the index of compression; (4)

(ii) the volumetric efficiency; (3)

(iii) the indicated work per kg of air; (3)

(iv) the free air capacity in m^3/min, given that free air conditions are 1.013 bar and 25°C. (4)

Note: For air, R = 0.287 kJ/kg K.

9. (a) Explain why impulse turbine nozzles have convergent-divergent form. (4)

(b) Air expands isentropically in a convergent-divergent nozzle. The pressure at nozzle inlet is 15 bar and the inlet temperature is 450 K. The outlet pressure is 5 bar. The mass flow rate is 6.5 kg/s.

Determine EACH of the following:

(i) the throat area; (6)

(ii) the exit area. (6)

Note: $p_c = p_0 \times \left(\dfrac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$; $T_c = T_0 \times \left(\dfrac{2}{\gamma+1}\right)$; $a = \sqrt{\gamma R T}$

For air, R = 0.287 kJ/kg K and γ = 1.4.

041-32 APPLIED HEAT | **Data Sheet Q6** | **Paper 71**

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***