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 21 JULY 2014

1315 - 1615 hrs

Examination paper inserts:

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. Air initially at a pressure of 1 bar and a temperature of 273 K undergoes the following cycle of steady flow processes: isothermal expansion to a pressure of 0.70 bar, followed by isentropic compression to the initial pressure, and then cooling at constant pressure to the initial temperature.

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

   (b) Calculate EACH of the following:

   (i) the temperature after compression; (2)

   (ii) the heat transfer per kg during cooling; (2)

   (iii) the net specific work transfer in the cycle; (4)

   (iv) the coefficient of performance of the cycle, regarded as a heat pump. (2)

   Note: For air, $\gamma = 1.4$ and $R = 0.287$ kJ/kg K.

2. A gaseous fuel consists of a mixture of methane (CH_4), 80% by volume, and pentane (C_5H_{12}), 20% by volume. It is burned in 10% excess air. The dry combustion gases contain 1% carbon monoxide (CO) by volume.

   (a) Formulate the full combustion equation per kmol of fuel. (13)

   (b) Calculate the percentage by volume of O_2 in the dry combustion products. (3)

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

3. The layout of a gas turbine plant is illustrated in Fig. Q3. The plant operates between pressures of 1.00 bar and 23.00 bar. The HP turbine drives the compressor, and the LP turbine drives the load. Air enters the compressor at temperature of 300 K. Combustion gases enter the HP turbine at 1530 K. The isentropic efficiency of the compressor is 0.80, and that of each turbine is 0.90. For the compression process, $\gamma = 1.4$ and $c_P = 1.005$ kJ/kg K. For the remaining processes, $\gamma = 1.33$ and $c_P = 1.150$ kJ/kg K. The mass flow rate of exhaust gas is 110 kg/s, and the calorific value of the fuel is 40 MJ/kg.

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

(b) Calculate EACH of the following:

(i) the temperature and pressure at HP turbine exhaust; (6)

(ii) the power output; (3)

(iii) the specific fuel consumption in kg/kWh. (3)

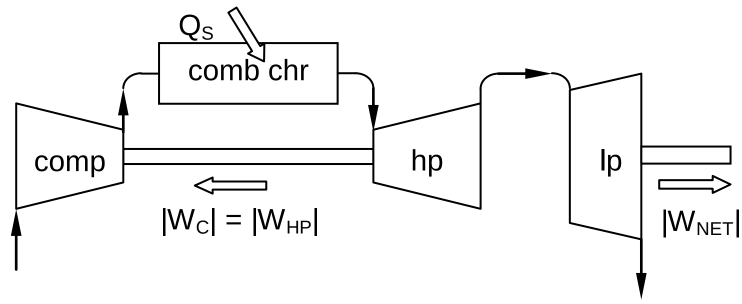

Fig Q3

4. A regenerative steam power cycle operates between pressures of 70 bar and 0.05 bar. The maximum temperature is 580°C. The optimum mass of steam is bled for feed heating at a pressure of 2 bar. A direct mixing feed heater is used. Expansion in the turbine and compression in the feed pumps are isentropic.

(a) Sketch the T-s diagram for the cycle. (5)

(b) Determine for the cycle EACH of the following:

(i) the specific work output (taking account of feed pump work); (9)

(ii) the thermal efficiency. (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 blade velocity is 235 m/s. All the blades are symmetrical, and blade friction is negligible. The axial velocity component remains constant throughout the stage.

(a) Sketch the combined velocity diagrams for each moving row, labelling velocities and angles. (6)

(b) Determine EACH of the following:

(i) all the blade angles; (6)

(ii) the diagram efficiency. (4)

6. Ammonia (R717) is used as the refrigerant in a simple vapour compression cycle to maintain the contents of a container at a temperature of 8°C. The temperature of the surroundings is 34°C. To achieve the required heat transfer, the temperature difference between the cold container and the evaporating refrigerant should be 6 K and the temperature difference between the condensing refrigerant and the surroundings should be 10 K. The refrigerant enters the compressor dry and saturated, and there is no undercooling in the condenser. The isentropic efficiency of the compressor is 0.85.

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

(b) Determine EACH of the following:

(i) the evaporating and condensing pressures; (2)

(ii) the temperature at compressor outlet; (6)

(iii) the coefficient of performance of the cycle. (3)

7. River water is to be used to cool engine cooling water in a single pass shell and tube heat exchanger. The cooling water is to enter the tubes at a temperature of 85°C and to be cooled to 28°C. The flow rate of cooling water will be 2.5 kg/s. The river water will enter at a temperature of 14°C and its flow rate will be 15 kg/s. The specific heat capacities of both cooling water and river water may be taken as 4.2 kJ/kg K. The overall heat transfer coefficient is expected to be 3200 W/m^2 K, based on the outside surface area of the tubes. The tube outside diameter is to be 60 mm.

Calculate EACH of the following:

(a) the outlet temperature of the river water; (3)

(b) the logarithmic mean temperature difference for EACH of the following cases:

(i) counter flow; (3)

(ii) parallel flow; (3)

(c) the total length of tubing required for EACH of the following cases:

(i) counter flow; (4)

(ii) parallel flow. (3)

8. At the beginning of compression in a single stage, single acting reciprocating air compressor, the air is at a pressure of 1.03 bar and a temperature of 35°C. The delivery valve opens at a pressure of 8.3 bar. The delivery temperature is 195°C. The bore diameter and stroke length are 0.48 m and 0.53 m respectively. The clearance volume is 5.2% of the swept volume and the compressor runs at 600 rev/min.

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

(b) Calculate 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) State why impulse turbine nozzles have convergent-divergent form. (2)

(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 4 bar. The mass flow rate is 8.5 kg/s.

Calculate EACH of the following:

(i) the throat area; (7)

(ii) the exit area. (7)

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

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

refrigerant:	*CO_2*									
saturation values							*superheat (T - T_s)*			
							50 K		100 K	
T	p_s	v_g	h_f	h_g	s_f	s_g	h	s	h	s
(°C)	(bar)	(m³/kg)	(kJ/kg)		(kJ/(kg K))		(kJ/kg)	(kJ/(kg K))	(kJ/kg)	(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***