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, 18 OCTOBER 2010

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 for which $R = 0.287$ kJ/kg K and $\gamma = 1.33$ expands reversibly in a cylinder according to the law $pV^{1.48} =$ constant and then heated at constant volume. The initial pressure is 88 bar, the initial temperature is 1727°C and the final pressure is 1.5 bar. The final volume is twenty times the initial volume.

   (a) Sketch the processes on p-V and T-S diagrams. (4)

   (b) Determine EACH of the following:

   (i) the temperature after expansion; (2)

   (ii) the final temperature; (2)

   (ii) the net heat transfer per kg; (5)

   (iv) the net change in specific entropy. (3)

2. The following data refer to a 20 cylinder 4-stroke diesel engine under test:

bore diameter	280 mm
stroke length	330 mm
speed of rotation	1000 rev/min
brake torque	86 kN m
fuel consumption	1.71 tonne/h
calorific value of fuel	42 MJ/kg

The fuel supply to each cylinder is cut off in turn, and the brake torque is adjusted each time so that the speed returns to 1000 rev/min. The mean value of the torques thus measured is 81.23 kN m.

Determine EACH of the following:

(a) the brake power; (2)

(b) the mechanical efficiency; (5)

(c) the brake specific fuel consumption (kg/kW h); (2)

(d) the average value of indicated mean effective pressure; (4)

(e) the brake thermal efficiency. (3)

3. The mass analysis of a fuel is: carbon 78%; hydrogen 16%; sulphur 3.2%; water 2% (remainder ash).

Determine EACH of the following:

(a) the theoretical air/fuel ratio by mass; (6)

(b) the volumetric analysis of the dry products (ie excluding H_2O and soluble SO_2) when the fuel is burned completely in 30% excess air; (6)

(c) the dew point temperature of the combustion products if the total pressure is 1.03 bar. (4)

Note: atomic mass relationships: H = 1; C = 12; O = 16; N = 14; S=32
Air contains 21% oxygen by volume and 23.3% oxygen by mass.

4. A steam power plant consists of turbine, condenser, feed pump and boiler. Steam enters the turbine at a pressure of 50 bar and a temperature of 400°C, and expands to 0.2 bar, dryness fraction 0.9. The steam is then fully condensed without undercooling. Feed pump work may be disregarded. The boiler has an efficiency of 87%. The fuel used has a calorific value of 38 MJ/kg and contains 85% carbon by mass.

It is proposed that the plant be modified to incorporate “carbon capture”, which involves separating the CO_2 from the exhaust gas and pumping it to a storage facility. It is estimated that separating the CO_2 from the flue gases will require 19% of the turbine power output, and pumping the CO_2 will require 40 kJ per kg of CO_2.

Determine the overall thermal efficiency of the plant:

(a) before modification; (8)

(b) after modification. (8)

Note: relative atomic masses: C = 12; O = 16

5. (a) Define the term *degree of reaction* relating to a turbine stage. (2)

(b) In a 50% reaction turbine stage the steam leaves the fixed blades with a velocity of 280 m/s. The axial velocity component is 148.3 m/s and the blade velocity is 200 m/s.

Determine EACH of the following:

(i) the blade inlet and outlet angles; (5)

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

(iii) the diagram efficiency. (6)

6. A vapour compression cooling cycle using CO_2 operates between pressures of 18.5089 bar and 68.9182 bar. The refrigerant enters the compressor at a temperature of -18°C and leaves the condenser as saturated liquid. The temperature at compressor outlet is 103°C.

(a) Sketch the cycle on a p-h diagram. (3)

(b) Using Datasheet Q6, determine the coefficient of performance of the cycle. (6)

(c) State TWO disadvantages and THREE advantages of CO_2 as a refrigerant compared with other refrigerants such as halocarbons, hydrocarbons and ammonia. (7)

7. Wet steam at a pressure of 7.0 bar flows in a 5 m long pipe of inside diameter 38 mm and wall thickness 5 mm. The pipe is surrounded with a layer of lagging 15 mm thick. The thermal conductivity of the lagging is 0.05 W/m K and the outside surface heat transfer coefficient is 12 W/m^2 K. The outside air temperature is 30°C. The thermal resistances of steam film and pipe wall may be disregarded.

Determine EACH of the following:

(a) the rate of heat loss; (7)

(b) the outside surface temperature of the lagging; (3)

(c) the increase in the rate of heat loss which would result if the thickness of the lagging were reduced to 10 mm. (6)

8. A reciprocating compressor is to be used to compress methane (CH_4) which enters at a temperature of 300 K and a pressure of 0.95 bar. For safety reasons, the temperature of the methane is not to exceed 400 K. The index of compression is 1.3.

Determine EACH of the following:

(a) the specific gas constant R for methane; (2)

(b) the maximum pressure which can safely be obtained in a single stage; (2)

(c) the volumetric efficiency of the single stage machine if the clearance volume is 4.5% of the swept volume: (3)

(d) the maximum pressure which can safely be obtained using two stages with perfect intercooling; (3)

(e) the isothermal efficiency of the two stage machine. (6)

Note: atomic mass relationships: H = 1; C = 12
The universal gas constant is 8.314 kJ/kmol K

9. (a) Explain the term *choked flow* with reference to a convergent nozzle. (4)

(b) Air leaks into an evacuated vessel from the surroundings which are at a pressure of 1.00 bar. The passage through which the air leaks may be considered as a convergent nozzle with exit area 0.8 mm^2, and the flow within the passage may be assumed isentropic. The temperature of the surroundings is 25°C.

Determine the mass flow rate when the pressure in the vessel is:

(i) 0.5 bar; (6)

(ii) 0.8 bar. (6)

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

$$p_c = p_0 \times \left(\frac{2}{\gamma + 1} \right)^{\gamma/(\gamma-1)} ; \qquad a = \sqrt{\gamma R T}$$

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***