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

CHIEF ENGINEER REG.

APPLIED HEAT

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Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A perfect gas expands reversibly in a cylinder according to the law $pV^{1.5}$=constant and is then heated at constant volume.

   The initial pressure and temperature are 90 bar and 1800°C respectively.
   The final pressure is 2 bar and the final volume is twenty times the initial volume.

   (a) Sketch the processes on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the temperature after expansion; (2)

   (ii) the final temperature; (2)

   (iii) the net change in specific entropy. (8)

   Note: For the gas $R = 0.287$ *kJ/kgK and* $\gamma = 1.33$

2. A compression ignition engine working on the ideal dual combustion cycle has a volume compression ratio of 14:1.
   The pressure and temperature at the beginning of compression are 0.95 bar and 30°C respectively. The maximum pressure of the cycle is 44 bar and the constant pressure heat transfer takes place for 1/18 of the stroke.

   (a) Sketch the cycle on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following per unit mass of air:

   (i) the heat supply; (6)

   (ii) the heat rejected; (2)

   (iii) the net work output; (2)

   (iv) the thermal efficiency. (2)

   Note: For air $c_p = 1.005$ *kJ/kgK* $c_v = 0.718$ *kJ/kgK*

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3. A pure hydrocarbon fuel is completely burned in air.

The dry flue gas analysis shows they contain 15% carbon dioxide and 2.5% oxygen by volume.

(a) Determine the full combustion equation in kmols per kmol of fuel. (8)

(b) Calculate EACH of the following:

(i) the percentage mass analysis of the fuel; (4)

(ii) the gravimetric analysis of the wet exhaust gas. (4)

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

4. A steam power plant operates between a boiler pressure and temperature of 50 bar and 450°C respectively and a condenser pressure of 45 millibar.

The steam expands isentropically from the boiler pressure to a dry saturated condition, at which point some steam is bled off to a direct contact feed heater. The feed water leaves the heater at the saturation temperature of the bled steam pressure.

The remainder of the steam expands isentropically to the condenser pressure. There is 4 K of sub-cooling in the condenser and the feed pump work may be ignored.

(a) Sketch the cycle on a Temperature-specific entropy diagram. (3)

(b) Determine EACH of the following:

(i) the percentage moisture in the turbine exhaust; (4)

(ii) the mass flow rate of bled steam per kg of steam flowing; (5)

(iii) the thermal efficiency of the cycle. (4)

5. The first stage of an impulse turbine is a two row Curtis wheel.
Steam leaves the nozzles at 830 m/s and the blade speed is 180 m/s.
The first row of moving blade rows are symmetrical with a blade angle of 30°.
The velocity coefficient of 0.85 for all blade rows.
The outlet angles from the fixed blades and the second row of moving blades are 35° and 24° respectively.

(a) Draw to a scale of 1 mm = 5 m/s the velocity diagram for each row. (6)

(b) Determine EACH of the following:

(i) the nozzle angle to the plane of the wheel; (2)

(ii) the inlet angle to the second row of moving blades; (2)

(iii) the power output of the stage per kg of steam flowing; (3)

(iv) the diagram efficiency. (3)

6. The cooling load in a vapour compression refrigeration plant using CO_2 is 50 kW. At this load, the refrigerant enters the compressor at a pressure of 17.314 bar and temperature of -14°C. It is then compressed isentropically to a pressure of 54.65 bar and temperature of 68°C.
After cooling the refrigerant enters the expansion valve as a saturated liquid.
The density of the CO_2 at the compressor suction is 34.66 kg/m^3.
The four cylinder single acting compressor has a bore and stroke of 100 mm with a volumetric efficiency of 85%.

(a) Sketch the cycle on Pressure-specific enthalpy and Temperature-specific entropy diagrams. (4)

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

(i) the mass flow rate of refrigerant; (3)

(ii) the compressor power; (2)

(iii) the coefficient of performance; (2)

(iv) the compressor speed of rotation (5)

7. A furnace wall consists of fire-brick 440 mm thick supported externally by 10 mm thick steel plating.
The internal temperature of the furnace is 1500°C and the temperature of the surroundings is 25°C.
To reduce heat loss it is proposed to remove some of the firebrick and replace it with insulation. However, the maximum temperature the insulation can withstand is 850°C.

Calculate EACH of the following:

(a) the rate of heat loss per m^2 without insulation; (5)

(b) the maximum permissible thickness of the insulation; (6)

(c) the percentage reduction in heat loss when the insulation is fitted. (5)

Note: inner surface heat transfer coefficient = 10 W/m²K
thermal conductivity of the fire-brick = 1.6 W/mK
thermal conductivity of steel = 50 W/mK
thermal conductivity of the insulation = 0.45 W/mK
outer surface heat transfer coefficient = 5 W/m²K

8. A two-stage, single acting reciprocating compressor has a clearance volume of 4.5% of the swept volume in each stage. It is used to compress methane (CH_4).
The initial pressure and temperature are 0.95 bar and 25°C respectively and the maximum temperature of the methane must be limited to 150°C.
The polytropic index for each compression and expansion process process is 1.3 and inter-cooling is perfect.

(a) Sketch the process on a Pressure-Volume diagram indicating the work saved by inter-cooling. (2)

(b) Calculate EACH of the following:

(i) the interstage and delivery pressures; (2)

(ii) the volumetric efficiency of each stage; (2)

(iii) the specific work input; (4)

(iv) the isothemal efficiency. (6)

Note: Relative atomic masses H=1, C=12
The universal gas constant = 8.3145 kJ/kmolK

9. The volume of the shell of a steam condenser is 14.5 m^3.
The shell contains saturated water, dry saturated steam and air, all at a temperature of 39°C and vacuum gauge reading of 672 mm of mercury.
The mass of water present is 112 grammes.
After a period of time the temperature of the condenser shell rises to 50°C.
The atmospheric pressure remains constant at 996 mbar throughout the temperature change.

Determine EACH of the following:

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

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

(c) the partial pressure of the steam at 50°C; (4)

(d) the condition of the steam at 50°C; (3)

(e) the condenser pressure at 50°C. (4)

Note : for air R= 0.287 kJ/kgK
1 bar = 750 mm Hg

refrigerant: CO_2

							superheat ($T - T_s$)			
saturation values							50 K		100 K	
T	p_s	v_g	h_f	h_g	s_f	s_g	h	s	h	s
(°C)	(bar)	(m^3/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***