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, 7 APRIL 2014

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 expands reversibly in a cylinder according to the law $pV^{1.13}$ = constant and is then cooled at constant volume. The initial pressure is 60 bar, the initial temperature is 1500°C and the final pressure is 2.8 bar. The final volume is five times the initial volume.

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

   (b) Calculate EACH of the following:

   (i) the temperature after expansion; (2)

   (ii) the final temperature; (2)

   (iii) the total heat transfer per kg; (5)

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

   Note: For the gas, R = 0.189 kJ/kg K and γ = 1.23

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

bore diameter	83 mm
stroke length	92.4 mm
speed of rotation	2800 rev/min
brake torque	0.11 kNm
fuel consumption	7.65 kg/h
calorific value of fuel	35 MJ/kg
indicated MEP:	
cylinder 1	7.65 bar
cylinder 2	7.81 bar
cylinder 3	7.72 bar
cylinder 4	7.69 bar

Calculate 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 brake thermal efficiency; (3)

(e) the value to which the brake torque must be reduced to restore the speed to 2800 rev/min if the fuel supply to cylinder 1 is cut off. (4)

3. The mass analysis of a fuel is: carbon 80%; hydrogen 14%; sulphur 3%; water 3%.

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 1.0462 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 40 bar and a temperature of 450°C, and expands to 0.5 bar, dryness fraction 0.98. The steam is then fully condensed without undercooling. Feed pump work may be disregarded. The boiler efficiency is 90% and the calorific value of the fuel is 39.0 MJ/kg.

The condenser cooling water, which is used to supply heat to an industrial process, enters the condenser at a temperature of 50°C and leaves at a temperature of 70°C. The process heat requirement is 2 MW.

Determine EACH of the following:

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

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

(c) the power output of the steam plant; (2)

(d) the mass flow rate of fuel; (5)

(e) the condenser tube surface area required if the U-value is 2.8 kW/m^2 K. (5)

Note: for water, c_P = 4.2 kJ/kg K

5. (a) Define the term *degree of reaction* relating to a turbine stage. (3)

(b) In a 50% reaction turbine stage the steam leaves the fixed blades with a velocity of 299 m/s. The axial velocity component is 154 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. (5)

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 -16°C and leaves the condenser as saturated liquid. The temperature at compressor outlet is 80°C.

(a) Sketch the cycle on a p-h diagram. (4)

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

(c) Determine the isentropic efficiency of the compressor. (6)

7. Wet steam at a pressure of 12.0 bar flows in a 10 m long pipe of inside diameter 30 mm and wall thickness 4 mm. The pipe is surrounded with a layer of lagging 20 mm thick. The thermal conductivity of the lagging is 0.04 W/m K and the outside surface heat transfer coefficient is 15 W/m^2 K. The outside air temperature is 32°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 15 mm. (6)

8. A reciprocating compressor is to be used to compress CO_2 which enters at a temperature of 20°C and a pressure of 15.0 bar. The delivery temperature is not to exceed 100°C. The index of compression is 1.2.

Calculate EACH of the following:

(a) the specific gas constant R for CO_2; (2)

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

(c) the volumetric efficiency of the single stage machine if the clearance volume is 5% of the swept volume; (3)

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

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

Note: *atomic mass relationships: O = 16; 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 out of a pressure vessel to 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 0.5 mm^2, and the flow within the passage may be assumed isentropic. The temperature of the air in the vessel is 30°C.

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

(i) 2.0 bar; (6)

(ii) 1.2 bar. (6)

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

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