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 78 (as amended) CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY,11 JULY 2016

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. A theoretical engine cycle consists of the following four sequential processes:
compression according to the law $pV^{1.28}$ from the initial conditions;
constant volume heat addition;
expansion according to the law $pV^{1.33}$ to the initial volume;
constant volume heat rejection to the initial temperature.

The initial pressure and temperature are 1 bar and 43°C.

The volume compression ratio is 13:1.

The heat addition is 1200 kJ/kg of working fluid.

The working fluid has the properties of air throughout.

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

(b) Calculate EACH of the following:

(i) the heat transfer during the compression process; (6)

(ii) the heat transfer during the expansion process; (2)

(iii) the cycle efficiency. (4)

Note: for air c_v = 0.718 kJ/kgK, R = 0.287 kJ/kgK

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2. Air enters the compressor of simple gas turbine plant at a pressure and temperature of 1.013 bar and 298 K respectively and is compressed through a pressure ratio of 12:1 with an isentropic efficiency of 0.85.

The hot gases enter the turbine at a temperature of 1500 K and expand down to the initial pressure with an isentropic efficiency of 0.9.

The mass flow rate of air is 250 kg/min and the mass flow rate of fuel may be ignored.

(a) Sketch the cycle on a Temperature-specific entropy diagram. (2)

(b) Calculate EACH of the following:

(i) the compressor outlet temperature; (2)

(ii) the turbine outlet temperature; (2)

(iii) the net power output; (5)

(iv) the work ratio; (2)

(v) the thermal efficiency of the cycle. (3)

Note: for air $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*
for the hot gas $\gamma = 1.33$ *and* $c_p = 1.15$ *kJ/kgK*

3. A producer gas has the following volumetric composition: 49% H_2, 20% CH_4, 18% CO, 6% N_2, 4% CO_2, 2% C_3H_8, 1% O_2.

The gas is completely burned in 20% excess air.

Calculate EACH of the following:

(a) the volumetric air/fuel ratio for stoichiometric combustion; (6)

(b) the percentage volumetric analysis of the wet combustion products; (6)

(c) the gravimetric analysis of the dry products of combustion. (4)

Note: Relative atomic masses carbon = 12, hydrogen = 1, oxygen = 16, nitrogen = 14.
Air contains 21% oxygen by volume.

4. In a steam power plant, steam enters the turbine at a pressure and temperature of 60 bar and 500ºC respectively and expands to 0.08 bar dryness fraction 0.95.

There is 5.5 K sub-cooling in the condenser and the feed pump work may be ignored.

The boiler has an efficiency of 80% when burning fuel with a carbon content of 90% by mass and a calorific value of 39 MJ/kg.

The carbon dioxide in the exhaust gas is to be extracted which will reduce the work output by 1 MJ/kg CO_2 generated.

Calculate EACH of the following:

(a) the thermal efficiency of the plant before the CO_2 extraction takes place; (6)

(b) the mass flow of fuel per kg of steam produced; (2)

(c) the thermal efficiency when the CO_2 extraction takes place. (8)

5. The speed of rotation of a stage in a 50% reaction turbine is 4000 rev/min.

The mean blade velocity is 150 m/s and the mean blade height is 30 mm.

The blade speed ratio is 0.6 and the blade exit angle is 20º.

The specific volume of the steam at this stage is 0.65 m^3/kg.

(a) Sketch the velocity vector diagram for the stage and identify ALL velocities. (3)

(b) Calculate EACH of the following:

(i) the absolute velocity of the steam leaving the stage; (3)

(ii) the diagram efficiency for the stage; (3)

(iii) the mass flow of steam through the turbine in tonne/hour; (4)

(iv) the specific enthalpy drop across the stage. (3)

6. A vapour compression refrigeration plant using R134a operates between saturation temperatures of -20 °C and +25°C.

The plant produces 200 kg/hour of ice at -12 °C from water at +20°C.

The refrigerant enters the expansion valve at the rate of 531 kg/hour with 5 K of sub-cooling.

The isentropic efficiency of the compressor is 93.1%.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Calculate EACH of the following:

(i) the temperature of the refrigerant entering the compressor; (4)

(ii) the temperature of the refrigerant leaving the compressor; (6)

(iii) the cycle co-efficient of performance. (2)

Note: for water c_p = 4.187 kJ/kgK
for ice c_p = 2.1 kJ/kgK and enthalpy of fusion = 335 kJ/kg

7. An insulated container 3 m long, 2.4 m wide and 2.6 m high consists of an insulating layer of 200 mm thick cork placed between an inner layer of 5 mm thick aluminium and an outer layer of 5 mm thick steel.

The exposed surface of the aluminium is at -15°C when the outside atmosphere is at +25°C.

Calculate EACH of the following:

(a) the heat flow into the container per hour; (8)

(b) the interface temperatures between the cork and the steel; (3)

(c) the emissivity of the aluminium at -15°C when the contents of the container are at -25°C and the net emissive power from the aluminium is 15% of the value calculated in Q7(a). (5)

Note: thermal conductivity of aluminium = 205 W/mK
thermal conductivity of cork = 0.04 W/mK
thermal conductivity of steel = 54 W/mK
outer surface heat transfer coefficient =13 W/m^{2}K
Stefan-Boltzmann constant σ_{sb} = 56.7 x10^{-12} kW/m^{2}K^4

8. A two stage, single acting reciprocating air compressor is designed for minimum work and has perfect inter-cooling.

The pressure and temperature at inlet are 1 bar and 20°C respectively, the discharge pressure is 36 bar.

The swept volume of the first stage is 0.01 m^3 and the clearance volume is 3% of the swept volume.

The polytropic index for all the expansion and compression processes is 1.2, the mechanical efficiency of the compressor is 0.8 and the speed is 240 rev/min.

(a) Sketch the processes on a p-V diagram indicating the pressures and volumes. (4)

(b) Calculate EACH of the following:

(i) the first stage volumetric efficiency; (3)

(ii) the mass of air delivered per second; (4)

(iii) the input power. (5)

Note: for air R = 0.287 kJ/kgK

9. (a) State Dalton's law of partial pressures. (4)

(b) A reservoir containing a mixture of air and 375 grams of steam at a temperature of 250°C, has a volume of 0.6 m^3.

A gauge indicates a reservoir pressure of 2.1 bar when the atmospheric pressure is 744 mm of mercury.

Determine EACH of the following:

(i) the partial pressure of the steam; (4)

(ii) the mass of the air in the reservoir; (3)

(iii) the total enthalpy of the mixture. (5)

Note: for air *R = 0.287 kJ/kgK*, $\gamma = 1.4$
750 mm of Hg = 1 bar