CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY
MARINE ENGINEER OFFICER

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

040-32 - APPLIED HEAT

MONDAY, 14 OCTOBER 2019

1315 - 1615 hrs

Materials to be supplied by examination centres

Candidate's examination workbook Graph paper Thermodynamic and Transport Properties of Fluids (5th Edition) Arranged by Y.R. Mayhew and C.F.C. Rogers

Examination paper inserts:

Worksheet Q4 - Specific Enthalpy - Specific Entropy Diagram for Steam

Notes for the guidance of candidates:

1. Examinations administered by the SQA on behalf of the Maritime & Coastguard Agency.
2. Candidates should note that 96 marks are allocated to this paper. To pass, candidates must achieve 48 marks.
3. Non-programmable calculators may be used.
4. All formulae used must be stated and the method of working and all intermediate steps must be made clear in the answer.

Maritime & Coastguard Agency

SQA

APPLIED HEAT

Attempt SIX questions only

All questions carry equal marks

Marks for each part question are shown in brackets

All formulae used must be stated and the method of working and all intermediate steps must be made clear in the answer.

1. A mass of 1.55 kg of air at a pressure and temperature of 6 bar and 600°C respectively, expands in an isothermal process.

   At the end of expansion, the air is cooled at constant volume to a final pressure of 1.5 bar.

   The change of specific entropy during the isothermal process is 0.166 kJ/kgK.

   (a) Sketch the process on Pressure-Volume and Temperature-specific entropy diagrams. (2)

   (b) Calculate EACH of the following:

   (i) the net work transfer; (4)

   (ii) the net heat transfer; (6)

   (iii) the overall change in entropy. (4)

   Note: for air $R = 287$ *J/kgK*, $\gamma = 1.4$

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2. In a reversible heat engine cycle, air at a temperature of 45°C is compressed according to the law $Pv^{1.28}$ = Constant.

At the end of compression, 1200 kJ/kg of heat is added at constant pressure, after which, the air expands to the original volume according to the law $Pv^{1.33}$ = constant.

At the end of expansion, the air is cooled at constant volume to the original temperature.

The cycle volume compression ratio is 16:1.

(a) Sketch the cycle on Pressure-Volume and Temperature-specific entropy diagrams. (3)

(b) Calculate EACH of the following:

(i) the temperatures at the cardinal points; (4)

(ii) the specific net work transfer; (5)

(iii) the specific heat transfer at constant volume; (2)

(iv) the cycle thermal efficiency. (2)

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

3. Ethanol C_2H_5OH is completely burned with 34% excess air.

The combustion products are then cooled at a constant pressure of 1.5 bar to a temperature of 50°C.

Calculate EACH of the following:

(a) the mass analysis of the fuel; (2)

(b) air to fuel ratio by mass; (4)

(c) the mol fraction of the combustion products; (5)

(d) the mass of water condensed per 1 kg of fuel. (5)

Note: *atomic mass relationships C=12, O = 16, H = 1, N =14.*
air contains 23.3 % oxygen by mass.

4. A steam power plant using a reheat cycle is shown in Fig Q4.

Steam enters the High-Pressure Turbine at a pressure and temperature of 60 bar and 540°C respectively and expands with an isentropic efficiency of 87% to a pressure of 5 bar.

It is then reheated at constant pressure to a temperature of 470°C.

The Low-Pressure Turbine expands the steam to a pressure of 0.05 bar, the increase in specific entropy during this process is 0.3 kJ/kgK.

The feedwater leaves the condenser at a temperature of 27°C.

Under these conditions the plant produces a power output of 80 MW.

The feed pump work cannot be ignored.

(a) Draw the expansion and reheat process on Worksheet Q4. (5)

(b) Using Worksheet Q4, determine EACH of the following:

(i) the isentropic efficiency of the low pressure turbine; (2)

(ii) the mass flow rate of steam in tonne per hour; (5)

(iii) the cycle thermal efficiency. (4)

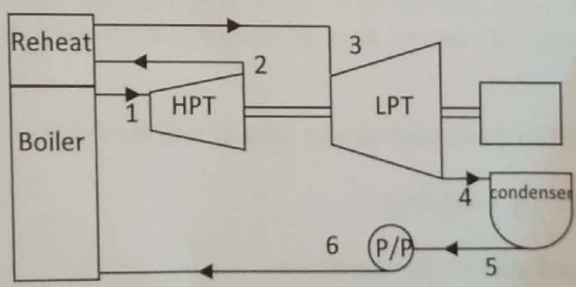

Fig Q4

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5. A stage in a 50% reaction turbine produces 750 kW at a speed of 6000 rev/min.

The mean blade ring diameter is 800 mm and the blade height is 40 mm.

The fixed blade exit angle is 20° and the absolute velocity of the steam at exit is in the axial direction.

The steam pressure in the stage is 3 bar.

(a) Sketch the stage velocity vector diagram indicating all the velocities. (3)

(b) Calculate EACH of the following:

(i) the absolute velocity of the steam entering the stage; (2)

(ii) the specific volume of the steam flowing in the stage; (6)

(iii) the steam temperature; (2)

(iv) the diagram efficiency. (3)

6. A vapour compression refrigeration plant fitted with an expansion valve uses ammonia as the working fluid.

The refrigerant enters the compressor at a pressure of 2.077 bar and is compressed in an isentropic process to a pressure and temperature of 12.37 bar and 132°C respectively. It enters the expansion valve with 6 degrees of subcooling.

Heat is removed from the condenser at the rate of 540 MJ/hour.

(a) Calculate EACH of the following:

(i) the compressor suction temperature; (4)

(ii) the compressor power; (4)

(iii) the cooling load; (2)

(iv) the coefficient of performance. (2)

(b) Sketch the cycle on a Temperature-specific entropy diagram showing the temperatures at the cardinal points. (4)

7. A 15 mm thick steel furnace cover is in the form a hemisphere and has an internal diameter of 1.65 m.

The internal surface is coated with a refractory material 125 mm thick which has an inner surface temperature of 800°C.

The external surface is coated in a layer of magnesia insulation 60 mm thick which has an outer surface temperature of 40°C.

The magnesia is to be covered in an additional layer of insulation to reduce the heat flow by 50%.

The inner and outer surface temperatures are to remain at 800°C and 40°C respectively.

Calculate EACH of the following:

(a) the heat flow through the original three layers; (6)

(b) the thickness of the additional insulating layer; (6)

(c) the change in temperature at the steel/magnesia interface. (4)

Note: *thermal conductivity refractory = 0.3 W/mK*
thermal conductivity steel = 50 W/mK
thermal conductivity magnesia = 0.05 W/mK
thermal conductivity insulation = 0.03 W/mK

8. A four-stage single acting reciprocating air compressor is designed for minimum work with perfect intercooling.

The inlet pressure and temperature is 1.0129 bar and 32°C respectively, the delivery pressure is 152 bar.

The clearance is negligible and the polytropic index of compression for each stage is 1.28.

(a) Calculate EACH of the following per kilowatt of indicated power:

(i) the free air delivery at 1 bar and 0°C; (6)

(ii) the isothermal efficiency of the machine; (3)

(b) Sketch the cycle on a pressure-Volume diagram showing EACH of the following:

(i) the stage pressures; (3)

(ii) the isothermal curve; (1)

(iii) the work saved by intercooling. (3)

Note: for air $c_p = 1.005$ *kJ/kgK and* $R = 0.287$ *kJ/kgK*

9. A horizontal section of fire main is made from a 100 mm internal diameter rigid steel pipe and is terminated by a 40 mm diameter nozzle, open to the atmosphere.

The flow through the nozzle is controlled by a valve with an on/ off action.

The fire main contains sea water maintained at a pressure of 7 bar(gauge).

(a) Calculate EACH of the following when the valve is fully open:

(i) the mass flow through the nozzle; (6)

(ii) the force exerted on the fire main by the nozzle. (6)

(b) Calculate the instantaneous pressure in the fire main when the valve switches from fully open to fully closed. (4)

Note: *for sea water density* $\rho = 1025$ *kg/m*^{3}*, Bulk modulus* $K = 2.34 \times 10^9$ *N/m*^{2}*.*

For the pipe $\frac{c^2}{2} = \frac{(\delta p)^2}{2K\rho}$

c = Fluid velocity, K = Bulk modulus, ρ *= Fluid density,*
δp *= Change of pressure.*