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, 9 DECEMBER 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:

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 2 kg of carbon dioxide at a pressure and temperature of 12 bar and 800°C respectively, expands in an isentropic process to a pressure of 2 bar.

   It is then cooled at constant pressure to a temperature of 15°C.

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

   (b) Calculate EACH of the following:

   (i) the net-work transfer; (5)

   (ii) the net-heat transfer; (3)

   (iii) the overall change in entropy; (3)

   (iv) the mean temperature of heat rejection. (3)

Note: Atomic mass relationships C= 12 O = 16
Universal gas constant R_o = 8.3145 kJ/kmol K
For Carbon dioxide γ = 1.33

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2. In the open cycle gas turbine plant shown in Fig Q2, turbine 1 drives the compressor and turbine 2 provides the power output.

At a particular operating condition:

The power output is 5 MW.

The combustion chamber exit temperature is 1500 K.

The temperature of the air entering the compressor is 15°C.

The isentropic efficiency of the compressor is 88% at a pressure ratio of 8:1.

The isentropic efficiency of each turbine is 85% at a pressure ratio of 8:1.

The mass flow of fuel and other system losses may be ignored.

Calculate EACH of the following:

(a) the mass flow of gas through turbine number 2; (5)

(b) the mass flow of air through the compressor; (8)

(c) the thermal efficiency of the plant. (3)

Note: for air $\gamma = 1.4$, $c_p = 1.005$ kJ/kgK
for gas $\gamma = 1.33$, $c_p = 1.15$ kJ/kgK

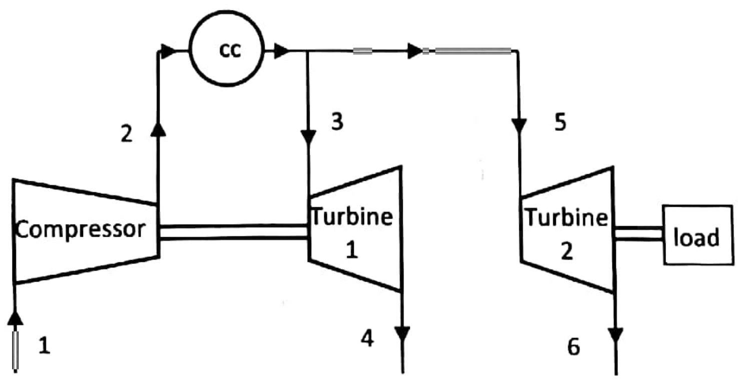

Fig Q2

3. A gaseous fuel has a volumetric composition of 20% CH_4, 24% H_2, 12% CO, 3% O_2 and 41% nitrogen.

It is completely burned in air with an air to fuel ratio of 6 to 1 by volume.

(a) Calculate the volumetric analysis of the combustion products. (7)

(b) Calculate EACH of the following for the dry combustion products:

(i) the characteristic gas constant; (3)

(ii) the specific heat at constant pressure; (4)

(iii) the adiabatic index. (2)

Note: atomic mass relationships $C = 12$, $O = 16$, $N = 14$. $H = 1$

Air contains 21 % oxygen by volume

Universal gas constant $R_o = 8.3145$ *kJ/kmolK*

For CO_2 $c_p = 0.939$ *kJ/kgK*

For N_2 $c_p = 1.044$ *kJ/kgK*

For O_2 $c_p = 0.941$ *kJ/kgK*

4. At entry to a throttle, a mass of 1 kg of wet steam has a pressure of 16 bar and volume of 0.1221 m^3.

It leaves the throttle at a pressure of 8 bar and expands in a hyperbolic process to a pressure of 1 bar.

(a) Calculate EACH of the following:

(i) the steam temperature at the throttle exit; (3)

(ii) the work transfer; (4)

(iii) the change of internal energy for the hyperbolic process; (4)

(iv) the final temperature of the steam. (2)

(b) Sketch the process on a Temperature-specific entropy diagram indicating the pressures and temperatures. (3)

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5. The nozzle angle of a two row Curtis wheel is 25° to the plane of rotation. The isentropic specific enthalpy drop in the nozzle is 312.5 kJ/kg and the isentropic efficiency is 90%.

The first row of moving blades has symmetrical blades.

The outlet angle of the fixed blades is half the inlet angle.

The second row of moving blades has an outlet angle designed so that the absolute velocity at stage exit is in the axial direction.

All the blades have a friction coefficient of 0.95 and the mean blade speed is 200 m/s.

(a) Calculate the absolute velocity of the steam leaving the nozzle. (2)

(b) Draw the moving blade velocity vector diagrams to a scale of 1 mm = 5 m/s. (6)

(c) Determine EACH of the following:

(i) the fixed and moving blade angles; (2)

(ii) the power output for a steam flow of 1 kg/s; (3)

(iii) the axial thrust for a stem flow of 1 kg/s. (3)

6. A vapour compression cycle using R134a as the working fluid is to be used as a heat pump.

The working fluid enters the compressor at a pressure and temperature of 2.006 bar and 0°C respectively with a specific volume of 0.1 m^3/kg. It leaves the compressor at a pressure and temperature of 7.7 bar and 50°C respectively and leaves the condenser at a temperature of 25°C.

The compressor has a swept volume of 5.556×10^{-4} m^3 and a volumetric efficiency of 90% at a speed of 300 rev/min.

The air cooling the condenser has flow rate of 25.73 m^3/min.

The temperature of the air flowing over the evaporator falls by 8 degrees.

(a) Sketch the cycle on Pressure-specific enthalpy and Temperature-specific entropy diagrams, inserting the values on the pressure and temperature axes. (4)

(b) Calculate EACH of the following:

(i) the compressor power; (4)

(ii) the coefficient of performance; (2)

(iii) the volume of air flowing over the evaporator; (3)

(iv) the temperature rise of the air flowing over the condenser. (3)

Note: for air c_p = 1.005 kJ/kgK, density = 1.177 kg/m^3

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7. A steam pipe 150 m in length has an internal diameter 150 mm and wall thickness of 15 mm is covered in a layer of insulation 50 mm thick.

Dry saturated steam enters the pipe at a pressure of 20 bar with a flow rate of 750 kg/hour.

The ambient temperature is -10°C.

Calculate EACH of the following:

(a) the overall heat transfer coefficient of the pipe; (4)

(b) the heat lost from the pipe per hour; (2)

(c) the mass of steam condensed per hour; (6)

(d) the percentage change in the steam velocity between inlet at exit. (4)

Note: inner surface heat transfer coefficient = 8 W/m²K
thermal conductivity of steel = 55 W/mK
thermal conductivity of the insulation = 0.05 W/mK
outer surface heat transfer coefficient = 14 W/m²K

8. A single stage single acting reciprocating air compressor has a bore of 250 mm and stroke of 400 mm.

The inlet pressure and temperature are 95 kN/m² and 30°C respectively, the delivery pressure is 950 kN/m².

The compressor has a volumetric efficiency of 82.5% at a speed of 300 rev/min.

The polytropic index of expansion and compression is 1.28.

The mechanical efficiency of the drive train is 90%.

(a) Sketch the cycle on a Pressure-volume diagram identifying the volumes. (3)

(b) Calculate EACH of the following:

(i) the clearance ratio; (3)

(ii) the compressor input power; (4)

(iii) the rate of heat rejection during the compression process. (6)

Note: for air $\gamma = 1.4$

9 A tank containing lubricating oil has two sharp edge orifice outlets on one side.

The upper orifice has a diameter of 20 mm and its centre is located 1.275 m below the surface of the oil. The centre of the lower orifice is located 2.8 m below the surface.

The oil level in the tank in maintained constant and the mass flow rate through each nozzle is the same.

Calculate EACH of the following:

(a) the mass of oil flowing into the tank per hour; (8)

(b) the diameter of the lower orifice. (8)

Note: *for oil* $\rho = 850\ kg/m^3$

for the upper orifice $C_v = 0.97,\ C_c = 0.67$

for the lower orifice $C_v = 0.91,\ C_c = 0.72$