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, 13 JULY 2020

1315 - 1615 hrs

Materials to be supplied by examination centres

Candidate's examination workbook Graph paper Thermodynamic and Transport Properties of Fluids (5^{th} 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 1 kg of argon at a pressure and temperature of 20 bar and 127°C respectively, expands in an isentropic process to a pressure of 2 bar.

   It is then compressed to the original pressure according to the law PV^n= constant. The overall decrease in entropy is 0.217 kJ/K.

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

   (b) Calculate EACH of the following:

      (i) the temperature at the end of compression; (3)

      (ii) the polytropic index of compression; (4)

      (iii) the net work transfer; (4)

      (iv) the net heat transfer. (3)

   Note:for Argon $\gamma = 1.67$, $c_p = 520.3\ J/kgK$

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2. An open cycle gas turbine plant with a regenerator is shown in Fig Q2.

The air enters the compressor at a pressure and temperature of 1 bar and 17°C respectively. It is compressed with an isentropic efficiency of 0.82 to a pressure of 6 bar.

The combustion gas enters the turbine at a temperature of 827°C and is expanded with an isentropic efficiency of 0.88 to a pressure of 1 bar.

The regenerator is fitted with a bypass and may be considered as a perfect heat exchanger.

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

(a) Calculate EACH of the following:

(i) the specific net-work output; (6)

(ii) the decrease in thermal efficiency when the regenerator is fully bypassed. (6)

(b) Sketch the cycle on a Temperature-specific entropy diagram showing the effect of the regenerator. (4)

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

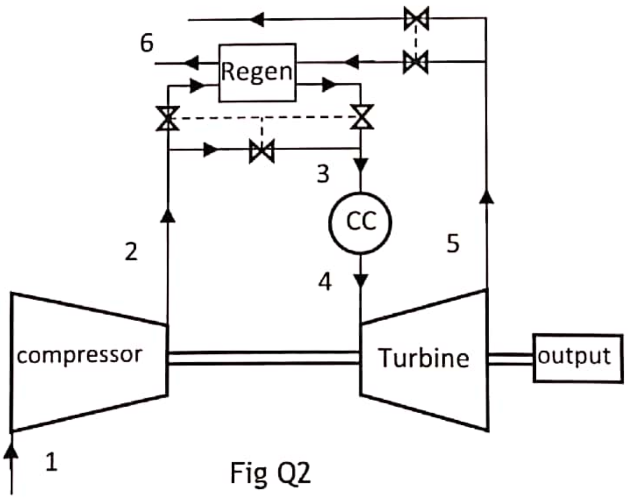

Fig Q2

3. A rigid vessel contains 9 kg of oxygen and 33.9 kg of nitrogen at a pressure and temperature of 2 bar and 52°C respectively.

100 kg of methane (CH_4) is pumped into the vessel resulting in a uniform mixture of gases at a temperature of 2°C.

Calculate EACH of the following:

(a) the volume of the vessel; (4)

(b) the final pressure of the mixture; (6)

(c) the difference in the internal energy of the initial and final mixtures. (6)

Note: *atomic mass relationships C = 12, O = 16, N = 14, H = 1*
universal gas constant $R_o = 8.3145$ *kJ/kmolK*
for O_2 $c_v = 0.6632$ *kJ/kgK*
for N_2 $c_v = 0.7431$ *kJ/kgK*
for CH_4 $c_v = 1.671$ *kJ/kgK*

4. The shell of a steam condenser has a volume of 10 m^3 and contains dry saturated steam and air.

At a particular instant the vacuum gauge reads 660 mm of mercury and the internal temperature is 38°C.

After a period of time the temperature has fallen to 26.7°C and the vacuum gauge reads 560 mm of mercury.

The atmospheric pressure remains constant 1014 mbar.

Calculate EACH of the following:

(a) the initial mass of air present; (5)

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

(c) the mass of air that has leaked into the condenser; (5)

(d) the mass of vapour condensed. (4)

Note: *for mercury* $\rho = 13600$ kg/m^3
for air $R = 287$ *J/kgK*

5. Steam flows through one stage of a pressure compounded impulse turbine at the rate of 1.5 tonne /hour.

The steam enters the nozzles with a velocity of 170 m/s and a pressure and temperature of 30 bar, 400°C respectively.

The nozzles are set at 20° to the plane of rotation and expand the steam with an isentropic efficiency of 95% to a pressure of 15 bar.

The blades have an exit angle 10° less than their inlet angle and a velocity coefficient of 0.9.

(a) Calculate the absolute velocity of the steam leaving the nozzles. (4)

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

(c) Determine EACH of the following for the stage:

(i) the diagram power; (2)

(ii) the axial thrust; (2)

(iii) the diagram efficiency. (2)

Note: Blade speed ratio = $\frac{\cos\alpha_1}{2}$

6. A vapour compression refrigeration plant is used to produce ice at -15°C from fresh water at 20°C.

The R134a refrigerant is compressed in an isentropic process from suction conditions of 1.3272 bar, -10°C to a discharge pressure of 10.163 bar.

The temperature rise of the condenser fresh water cooling is 10 K at a flow rate of 22 tonne/hour.

The refrigerant enters the expansion valve at a temperature of 30°C.

(a) Sketch the cycle on Pressure-specific enthalpy and Temperature-specific entropy diagrams. (2)

(b) Calculate EACH of the following:

(i) the compressor discharge temperature; (4)

(ii) the mass flow rate of refrigerant required; (5)

(iii) the rate of ice production in tonne per hour. (5)

Note: for fresh water c = 4.2 kJ/kgK
for ice c = 2.1 kJ/kgK, enthalpy of fusion = 335 kJ/kg

7. A furnace wall is made from 10 mm thick steel plate lined internally with refractory 100 mm thick. The external surface is a sheet steel casing, creating a 200 mm wide air gap.

A 40% reduction in heat loss is to be achieved by insulating the external side of the furnace wall, while the position of the sheet steel casing remains unchanged.

The internal surface temperature of the refractory is 1800°C and the temperature of the surroundings remain constant at 25°C.

The effect of the sheet steel casing may be ignored.

(a) Calculate EACH of the following:

(i) the rate of heat loss per m^2 without insulation; (4)

(ii) the required thickness of insulation; (5)

(iii) the temperature drop across the final air gap. (4)

(b) Sketch the thermal gradient across the insulated wall showing the interface temperatures. (3)

Note:	*thermal conductivity of the refractory*	*= 0.31 W/mK*
	thermal conductivity of steel	*= 55 W/mK*
	thermal conductivity of air	*= 0.04 W/mK*
	thermal conductivity of the insulation	*= 0.023 W/mK*
	outer surface heat transfer coefficient	*= 11 W/m²K*

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8. A two stage single acting reciprocating air compressor is designed for minimum work and perfect intercooling.

The inlet pressure and temperature are 0.9 bar and 25°C respectively, the delivery pressure is 32.4 bar.

The free air capacity of the compressor is 8.5 m^3/min at a speed of 360 rev/min and a pressure and temperature of 1.013 bar and 0°C respectively.

The clearance ratio of each stage is 0.05 and the polytropic index for all compression and expansion processes is 1.28.

(a) Sketch the cycle on a Pressure-Volume diagram indicating the work saved by intercooling. (3)

(b) Calculate EACH of the following:

(i) the total volume of the low pressure cylinder; (5)

(ii) the indicated power of the machine; (3)

(iii) the power saved by intercooling. (5)

9 A rectangular plate has a mass of 5.45 kg and is suspended vertically by a hinge on the top horizontal edge. The centre of gravity of the plate is located 10 cm below the hinge.

A horizontal jet of fresh water 25 mm in diameter and flowing with a velocity of 5.65 m/s strikes the plate 15 cm below the hinge.

At this condition the plate is held in the vertical position by a compressed spring acting at its centre of gravity.

The flow rate of the jet is increased and the plate is deflected to an angle of 30° to the vertical against the spring force which remains constant.

Friction in the hinge may be ignored.

(a) Calculate EACH of the following:

(i) the spring force holding the plate vertical; (4)

(ii) the increase in the jet velocity required to deflect the plate. (8)

(b) Sketch the force diagram for the condition given in Q9(a)(ii). (4)