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, 15 JULY 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 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

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APPLIED HEAT

Attempt SIX questions only

All questions carry equal marks

Marks for each part question are shown in brackets

1. A mass of 1.2 kg of air at a pressure and temperature of 1 bar and 20°C respectively, is compressed isothermally through a volume ratio of 12:1. It is then compressed isentropically to a pressure of 48 bar.

   The two processes can be replaced by a single polytropic process operating between the same initial and final conditions.

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

   (b) Calculate EACH of the following:

   (i) the original total work transfer; (5)

   (ii) the polytropic work transfer; (5)

   (iii) the increase in heat transfer when the polytropic process is used. (4)

   Note: *for air* $\gamma = 1.4$, $R = 0.287$ kJ/kgK *and* $c_v = 0.718$ kJ/kgK

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

Air enters with an initial pressure and temperature of 1.0 bar and 15°C respectively and is compressed to a pressure of 9 bar.

The combustion products enter the high pressure stage at a pressure and temperature of 9 bar and 927°C respectively.

The turbine expands the gas in two stages of equal pressure ratio to the initial pressure.

The gas is reheated to 927°C between the turbine stages.

The compressor has an isentropic efficiency of 0.85.

Each turbine stage has an isentropic efficiency of 0.88.

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

(a) Calculate EACH of the following:

(i) the work ratio; (8)

(ii) the thermal efficiency. (4)

(b) Sketch the cycle on a Temperature-specific entropy diagram. (4)

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

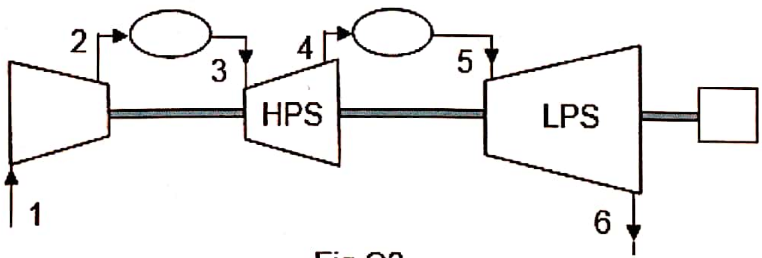

Fig Q2

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3. The composition of a natural gas by volume is 89.63% methane (CH_4), 6.32% ethane (C_2H_6), 2.16% propane (C_3H_8), 1.2% butane (C_4H_{10}), 0.69% Nitrogen (N_2).

It is completely burned at a pressure of 1.013 bar with 10% excess air by volume.

Calculate EACH of the following:

(a) the stoichiometric air supply for 100 kmols of natural gas; (4)

(b) the air fuel ratio by volume; (2)

(c) the mass analysis of the total combustion products; (6)

(d) the dew point temperature of the combustion products. (4)

Note: *atomic mass relationships H =1, C = 12, O = 16, N = 14.*
air contains 21% oxygen by volume.

4. A pressure vessel has a volume of 0.8 m^3 and contains steam at a pressure and temperature of 20 bar and 250°C respectively.

Steam is removed from the vessel until the pressure is 6 bar. The expansion of the steam during the removal process may be considered isentropic.

The vessel is then cooled until the pressure is 3 bar.

(a) Sketch the processes on a Temperature-specific entropy diagram. (4)

(b) Calculate EACH of the following:

(i) the mass of steam removed; (4)

(ii) the final dryness fraction of the steam; (3)

(iii) the heat transferred during cooling. (5)

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5. The first stage of an impulse turbine is a two row Curtis wheel.

Steam leaves the nozzles at a velocity of 550 m/s and an angle of 17° to the plane of rotation.

The blade speed is 125 m/s.

The first and second row of moving blades have symmetrical blading and the fixed blade outlet angle is 26°.

The blades have a velocity coefficient of 0.9.

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

(b) Determine EACH of the following:

(i) the moving blade inlet and outlet angles; (3)

(ii) the fixed blade inlet angle; (2)

(iii) the angle and absolute velocity of the steam leaving the stage; (2)

(iv) the diagram efficiency. (4)

6. A vapour compression refrigeration system operates between the pressures of 1.447 bar and 10.99 bar.

The ammonia refrigerant enters the compressor as a dry saturated vapour and is compressed with an isentropic efficiency of 93.9 %.

The compressor has a swept volume of 1.79 m^3/s and a volumetric efficiency of 90 %.

The refrigerent enters the expansion valve at a temperature of 24°C.

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

(b) Calculate EACH of the following:

(i) the temperature of the refrigerent at the compressor discharge; (5)

(ii) the heat removed in the condenser; (4)

(iii) the compressor power; (3)

(iv) the coefficient of performance when operating as a heat pump. (2)

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7. A steam pipe with a bore of 200 mm and wall thickness of 10 mm is 15 m long. It is covered with two layers of insulation, an inner layer 20 mm thick and an outer layer 15 mm thick.

Dry saturated steam at a pressure of 26 bar enters the pipe at a rate of 648 kg/hour.

The atmospheric temperature is 25°C.

Calculate EACH of the following:

(a) the rate of heat loss from the steam; (6)

(b) the outer surface temperature; (2)

(c) the mass of steam condensed per hour. (8)

Note: *inner heat transfer coefficient may be ignored*
thermal conductivity of steel = 52 W/mK
thermal conductivity of the inner insulation = 0.045 W/mK
thermal conductivity of the outer insulation = 0.15 W/mK
outer heat transfer coefficient = 10 W/m²K

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8. A single stage single acting reciprocating air compressor is to be replaced with a two stage single acting machine.

The two stage machine is designed for minimum work and has perfect intercooling.

The following conditions apply to both machines:

The suction conditions are 0.9 bar and 25°C.

The delivery pressure is 22.5 bar.

The index of compression in all the stages is 1.25.

The free air delivery is $0.07 m^3/s$ at a pressure of 1.01325 bar and temperature of 15°C.

The clearance volume in both machines may be ignored.

(a) Sketch the two stage cycle on a pressure Volume diagram showing the work saved by intercooling and the isothermal compression curve. (3)

(b) Calculate EACH of the following:

(i) the indicated power of the two stage machine; (4)

(ii) the power saved by using the two stage machine; (2)

(iii) the percentage reduction in the discharge temperature using the two stage machine; (4)

(iv) the isothermal efficiency of the two stage machine. (3)

9. A centrifugal pump runs at 500 rev/min and discharges sea water at the rate of $12 m^3/min$ against a head of 12 m.

The impeller has an inner diameter of 200 mm and an outer diameter of 500 mm.

At exit, the vanes are backward facing at an angle of 45° to the plane of rotation. The thickness of the vanes reduces the flow area by 10%.

There is no velocity of whirl at inlet and the fluid has a constant radial velocity of 2 m/s.

(a) Sketch the blade tip velocity vector diagram identifying the velocities. (4)

(b) Calculate EACH of the following:

(i) the width of the blade at inlet and exit; (4)

(ii) the angle of the blade at inlet; (3)

(iii) the manometric efficiency. (5)

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