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, 19 OCTOBER 2020

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 gas at a pressure of 2 bar and temperature of 27°C has a specific volume of 0.396 m^3/kg.

   The gas undergoes isentropic compression until the temperature is 604.2°C.

   The volume compression ratio is 16:1.

   It is then heated at constant pressure until the specific volume is 0.03885 m^3/kg.

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

   (b) Calculate EACH of the following:

   (i) the specific heats at constant pressure and constant volume; (4)

   (ii) the net specific work transfer; (4)

   (iii) the overall change in specific internal energy; (3)

   (iv) the overall change in specific entropy. (3)

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2. In the gas turbine plant shown in Fig Q2, the High Pressure Turbine drives the compressor and the Low pressure Turbine drives the load. There is reheat between the stages.

At a particular operating condition:

The High Pressure Turbine pressure ratio is 4.748:1.

The overall pressure ratio is 9:1.

The air enters the compressor at a temperature of 15°C.

The hot gas leaves the Combustion Chamber at 950 K and the ReHeater at 850 K.

The isentropic efficiency of the compressor is 85% and that of the Low Pressure turbine is 88%.

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

(a) Calculate EACH of the following:

- (i) the specific work output; 121.77 (4)
- (ii) the High Pressure Turbine outlet temperature; 668.1 (4)
- (iii) the thermal efficiency. 0.37 (4)

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

Note: *for air* $\gamma=1.4$ $c_p= 1.005\ kJ/kgK$
for gas $\gamma=1.33$ $c_p= 1.11\ kJ/kgK$

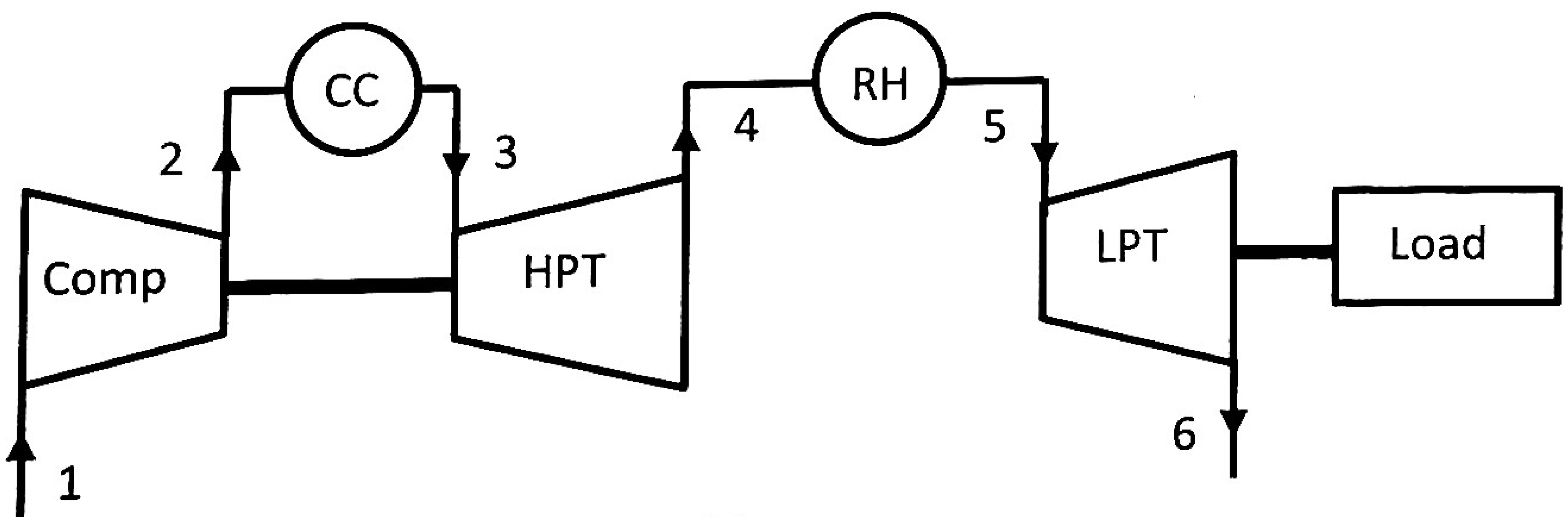

Fig. Q2

3. A fuel has a mass analysis of 52% carbon, 15% hydrogen and 33% oxygen.

A mass of 1 kg of the fuel is burned in air and the combustion products contain 0.233 kg of CO and 0.581 kg of O_2.

Use the equations of combustion by mass to calculate EACH of the following:

(a) the mass of carbon burned to CO_2; (4)

(b) the percentage excess air by mass; (6)

(c) the mol fraction of the total combustion products. (6)

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

4. Steam at a pressure and temperature of 20 bar and 400°C, enters a convergent divergent nozzle with negligible velocity.

The expansion is isentropic according to the law $PV^{1.55} = C$ to a pressure of 5 bar.

The nozzle throat diameter is 32.8 mm.

Calculate EACH of the following:

(a) the critical pressure; (3)

(b) the mass flow rate of steam through the nozzle; (5)

(c) the nozzle exit area. (8)

Note: for the nozzle $P_c = P_1 \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$

5. In one stage of a 50% reaction turbine, the pressure is 1 bar and the steam is dry saturated.

The blade exit angle is 20° and the blade speed ratio is 0.7.

The blade height is 8.5% of the mean blade ring diameter.

The stage develops 600 kW at a mass flow of 64.8 tonne/hour.

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

(b) Calculate EACH of the following:

(i) the mean blade speed; 140.66 (4)

(ii) the mean diameter of the blade ring; 1.281 (4)

(iii) the rotor speed; 2004.13 (2)

(iv) the blade inlet angle. 24.13 (3)

6. In the refrigeration plant shown in Fig Q6. A surface heat exchanger is used to cool the liquid entering the expansion valve. The operation of the heat exchanger may be considered to be adiabatic.

The refrigerant is ammonia and the compressor suction and discharge pressures are 2.465 bar and 11.67 bar respectively.

The refrigerant leaves the condenser as a saturated liquid and enters the expansion valve at a temperature of 18°C.

At the evaporator outlet, the refrigerant is a dry saturated vapour.

During compression the specific entropy increases by 0.24%.

(a) Calculate EACH of the following:

(i) the compressor suction temperature; (4)

(ii) the dryness fraction of the refrigerant entering the evaporator; (2)

(iii) the coefficient of performance of the cycle; (4)

(iv) the reversed Carnot cycle COP for the same pressures. (2)

(b) Sketch a Temperature-specific entropy diagram showing:

(i) the actual cycle; (2)

(ii) the reversed Carnot cycle operating between the same pressures; (1)

(iii) irreversible processes as dash lines. (1)

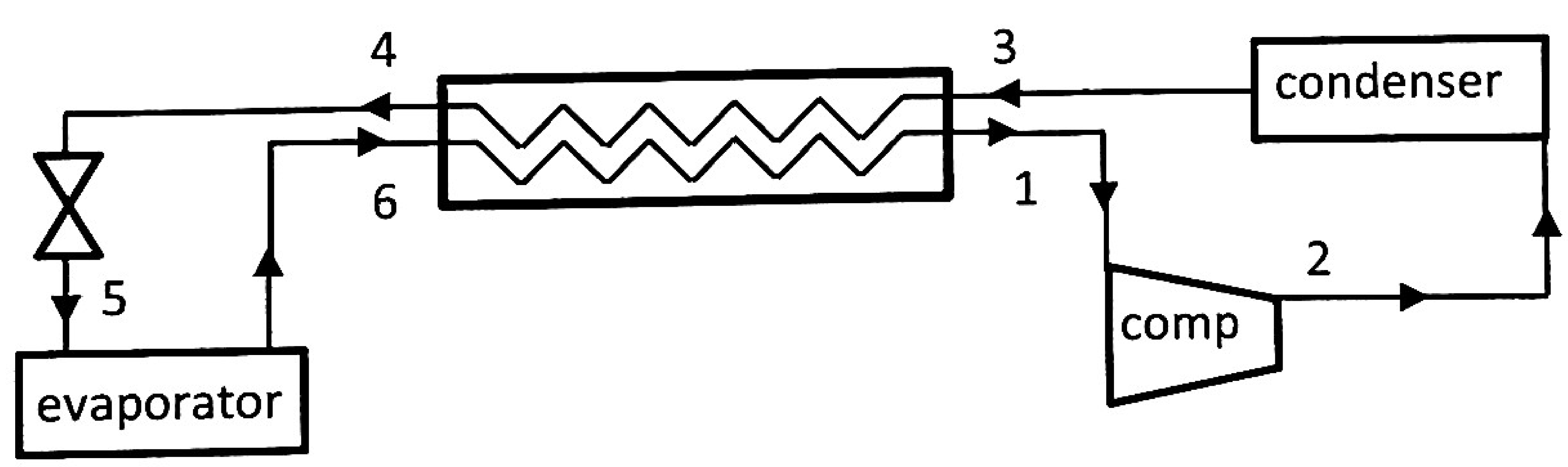

Fig. Q6

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7. A Primary superheater has a single pass, counter flow arrangement and operates at a steam pressure of 50 bar.

It has 60 tubes each with a mean diameter of 60 mm.

The gas flows through the tubes with a velocity of 1.5 m/s and enters with a temperature of 600°C and leaves with a temperature of 300°C.

Dry saturated steam enters the heater at the rate of 900 kg/hour.

(a) Calculate EACH of the following:

- (i) the heat transferred from the gas to the steam; 96.237 (3)
- (ii) the log meant temperature difference; 80.01 (5)
- (iii) the length of an individual tube. .98 (5)

(b) Sketch the heat exchanger temperature profile diagram. (3)

Note : *the specific heat capacity of steam* c_{steam} = *2.07 kJ/kgK*
the gas side heat transfer coefficient = *0.229 kW/mK*
the steam side heat transfer coefficient = *0.2 kW/mK*
the specific heat capacity of the gas c_p = *1.11 kJ/kgK*
the density of the gas = 1.136 kg/m^3

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

The inlet pressure and temperature are 1 bar and 17°C respectively and the discharge pressure is 64 bar.

In all stages, the polytropic index of expansion and compression is 1.3 and the clearance ratio is 0.05.

The low pressure cylinder bore is 250 mm and the stroke is 300 mm.

(a) Calculate EACH of the following:

- (i) the interstage pressures; (2)
- (ii) the induced volume in litres per revolution; (3)
- (iii) the indicated work; (3)
- (iv) the heat removed in the intercoolers. (5)

(b) Sketch the cycle on a Pressure-volume diagram showing the pressures and the work saved by intercooling. (3)

Note: *for the gas* c_p= *0.5203 kJ/kgK, molecular mass M = 39.948 kg/kmol*
the universal gas constant = 8.3145 kJ/kmolK

9. A fluid flows through a venturi meter which is inclined at 30° from the vertical.

The inlet has diameter of 200 mm and is located below the throat which has a diameter of 80 mm.

The distance between the inlet and throat measured along the venturi centre line is 160 mm.

The differential pressure is measured by a U tube manometer with the branches in contact with the meter fluid.

The level difference in the manometer is constant at 300 mm of mercury.

Calculate EACH of the following:

(a) the differential pressure; (3)

(b) the increase in kinetic energy between the inlet and the throat; (5)

(c) the fluid velocities at the inlet and throat; (4)

(d) the mass flow rate of fluid in tonnes per hour. (4)

Note: Relative density of mercury = 13.6.
Relative density of fluid = 0.88.
Coefficient of discharge $C_d = 0.97$