

**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, 24 AUGUST 2020

1315 - 1615 hrs

Materials to be supplied by examination centres

Candidate's examination workbook Graph paper Thermodynamic and Transport Properties of Fluids (5 <sup>th</sup> Edition) Arranged by Y.R. Mayhew and C.F.C. Rogers
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Examination paper inserts:

Worksheet Q4 Specific Enthalpy - Specific Entropy Chart for Steam
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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.

## 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 air at a pressure and temperature of 64 bar and 758°C respectively, is heated at constant volume until the pressure is 167 bar.

The air then expands in a polytropic process to a final pressure and volume of 4 bar and 0.832 m<sup>3</sup>.

- (a) Sketch the processes on Pressure-Volume and Temperature-specific entropy diagrams, showing the given data. (2)
- (b) Calculate EACH of the following:
- (i) the polytropic index of expansion; (2)
  - (ii) the change of internal energy for EACH process; (5)
  - (iii) the net work transfer; (2)
  - (iv) the overall change in entropy. (5)

Note: for air  $\gamma = 1.4$ ,  $R = 287 \text{ J/kgK}$

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2. An air standard dual combustion cycle has a volume compression ratio of 18:1.

The pressure and temperature at the beginning of compression are 2 bar and 40°C respectively.

The constant volume heat addition is 300 kJ/kg and the constant pressure heat addition occurs for 3% of the stroke.

Calculate EACH of the following:

- (a) the pressure and temperature at the cardinal points of the cycle; (6)
- (b) the theoretical mean effective pressure; (6)
- (c) the air standard efficiency. (4)

*Note: for air  $c_v = 0.7175$  kJ/kgK,  $c_p = 1.0045$  kJ/kgK,  $\gamma = 1.4$*

3. A pure hydrocarbon fuel containing 86% carbon and 14% hydrogen by mass is burned in air.

The combustion products contain 2.79 kg CO<sub>2</sub> and 0.813 kg O<sub>2</sub> per kg of fuel burned.

Calculate EACH of the following:

- (a) the percentage mass of carbon burned to carbon monoxide; (4)
- (b) the percentage excess air; (6)
- (c) the mol fraction of the total combustion products. (6)

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

4. The steam plant shown in Fig Q4, operates on a regenerative cycle with reheat.

Steam expands in the High Pressure Turbine from a pressure and temperature of 60 bar and 540°C respectively to a pressure and temperature of 5 bar and 230°C respectively.

The steam is then reheated at constant pressure to a temperature of 470°C and then expands in the Low Pressure Turbine, to a pressure of 0.05 bar and dryness fraction of 0.99.

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

Bled steam enters the surface feed heater at a pressure of 5 bar and temperature of 230°C, it leaves as a saturated liquid.

The feed water leaves the heater at a temperature of 151.8°C.

The feed pump work may be ignored.

(a) Draw the expansion and reheat process on Worksheet Q4. (3)

(b) Sketch the cycle on a Temperature-specific entropy diagram. (3)

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

(i) the mass of bled steam per kg of steam leaving the boiler; (4)

(ii) the specific work output; (3)

(iii) the thermal efficiency. (3)

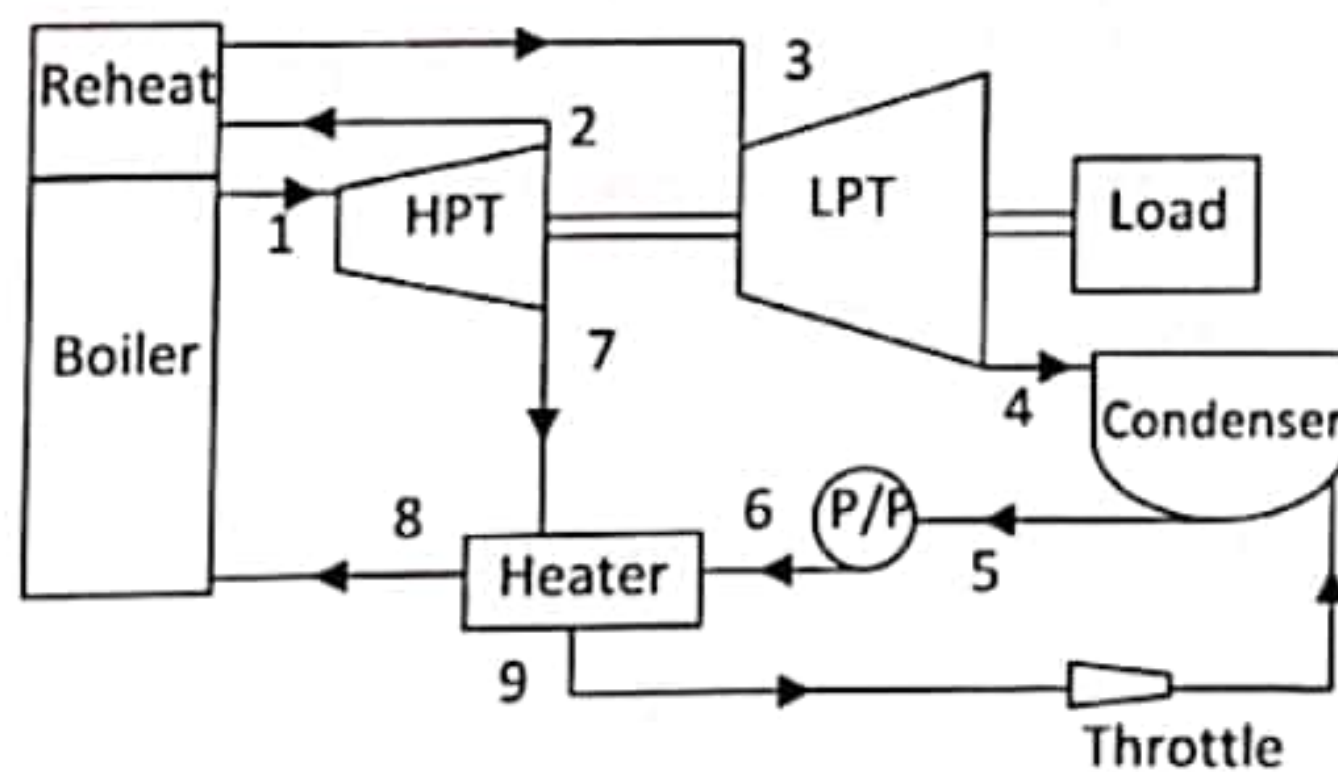


Fig Q4

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5. The steam condition at a stage in a 50% reaction turbine is 0.18 bar and 0.94 dry.

The stage develops a power of 1800 kW at speed of 4000 rev/min.

The mass flow of steam is 54 tonne/hour.

The fixed blades have an exit angle of  $21.5^\circ$  and the axial velocity is 79% of the blade speed at the mean blade radius.

- (a) Sketch the stage velocity vector diagram indicating the velocities. (3)
- (b) Calculate EACH of the following:
- (i) the mean diameter of the blade ring; (4)
  - (ii) the blade height; (4)
  - (iii) the diagram efficiency. (5)

6. A vapour compression refrigeration plant using ammonia is used to maintain the temperature of a cold room at  $-25^\circ\text{C}$  when the ambient conditions are  $30^\circ\text{C}$ .

The cold room bulkheads have an overall thermal conductivity of  $0.5 \text{ W/m}^2\text{K}$  and a total surface area of  $162 \text{ m}^2$ .

The ammonia enters the compressor as a dry saturated vapour at  $-28^\circ\text{C}$  and leaves at a pressure and temperature of 9.134 bar and  $122^\circ\text{C}$ . It enters the expansion valve at a temperature of  $22^\circ\text{C}$ .

The two cylinder single acting compressor has a bore of 76 mm and a stroke of 80 mm and runs at a speed of 320 rev/min.

- (a) Sketch the cycle on a Temperature-specific entropy diagram showing ALL the temperatures. (3)
- (b) Calculate EACH of the following:
- (i) the cooling load; (2)
  - (ii) the cycle coefficient of performance; (4)
  - (iii) the Carnot cycle coefficient of performance when operating between the same pressures; (2)
  - (iv) the volumetric efficiency of the compressor. (5)

7. An annular water jacket surrounds a 200 mm mean diameter pipe carrying a hot gas, in a counter flow arrangement.

The hot gas enters the cooler with a velocity of 3 m/s and a temperature of 527°C, it leaves at a temperature of 50°C.

The cooling water enters the cooler at 15°C and has a flow rate of 900 kg/hour.

The wall thickness of the pipe may be ignored.

(a) Calculate EACH of the following:

(i) the rate of heat transfer across the cooler; (2)

(ii) the exit temperature of the water; (2)

(iii) the log mean temperature difference; (4)

(iv) the length of the cooler. (5)

(b) Sketch the cooler temperature profile diagram. (3)

Note: for cooling water  $c = 4.19 \text{ kJ/kgK}$

for the hot gas  $c_p = 1.169 \text{ kJ/kgK}$ , specific volume =  $1.493 \text{ m}^3 / \text{kg}$

the inner surface heat transfer coefficient =  $0.2 \text{ kW/m}^2\text{K}$

the outer surface heat transfer coefficient =  $1.25 \text{ kW/m}^2\text{K}$

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8. A two-stage single acting reciprocating compressor is water cooled and runs at a speed of 240 rev/min.

The pressure and temperature at the first stage inlet are 1 bar and 15°C respectively. The second stage inlet conditions are 6 bar and 27°C.

The air leaves the machine at a pressure of 30 bar and temperature of 60°C.

The total mass of air in the low-pressure cylinder at the beginning of compression is 0.025 kg and the clearance ratio is 0.05.

The polytropic index for all expansion and compression processes is 1.25.

Calculate EACH of the following:

- (a) the total indicated power; (8)
- (b) the total heat removed per cycle from the cylinders; (5)
- (c) the total heat removed per cycle by the coolers. (3)

Note: for air  $\gamma = 1.4$ ,  $c_v = 0.7175 \text{ kJ/kgK}$

- 9 A centrifugal pump runs at 400 rev/min and delivers a liquid at the rate of 160 tonne per hour.

The impeller diameter is 900 mm and at exit the blades are backward facing at an angle of 30° to the plane of rotation.

There is no whirl at inlet and the fluid has a constant radial velocity through the impeller.

Suction is from a tank 1.2 m below the pump and delivery is to a tank 18.4 m above the pump.

The delivery pipe has an internal diameter of 200 mm, a length of 60 m and a friction factor coefficient of 0.06.

Valves and bends in the system create a loss equivalent to an additional 24 m of pipeline.

Suction line losses can be ignored.

Calculate EACH of the following:

- (a) the system total head; (7)
- (b) the pump power; (2)
- (c) the width of the impeller at exit. (7)

Note: for the fluid  $\rho = 900 \text{ kg/m}^3$