

**CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY –
MARINE ENGINEER OFFICER**

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 14 OCTOBER 2013

1315 - 1615 hrs

Examination paper inserts:

Worksheet Q4 (Enthalpy-Entropy Chart for Steam)

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. Air at a pressure of 1.02 bar and a temperature of 293 K is compressed polytropically in an engine cylinder from a volume of 0.2 m^3 to a volume of 0.02 m^3 . The pressure after compression is 40.6 bar. Heat is then supplied at constant pressure until the temperature is 1500 K.

- (a) Sketch the processes on p-V and T-S diagrams. (4)
- (b) Calculate EACH of the following:
- (i) the index of compression; (2)
- (ii) the temperature after compression; (1)
- (iii) the total heat transfer; (6)
- (iv) the total change in entropy. (3)

Note: For air, $\gamma = 1.4$ and $R = 0.287 \text{ kJ/kg K}$.

2. In an air standard Diesel cycle the volume at the end of heat supply is 1.80 times that at the beginning of heat supply. The temperature at the beginning of compression is 298 K, and that at the end of expansion is 678.6 K. The thermal efficiency is 66.9%.

- (a) Sketch the cycle on p-V and T-S diagrams. (4)
- (b) Calculate EACH of the following:
- (i) the heat supplied per kg; (3)
- (ii) the net work output per kg; (1)
- (iii) the maximum cycle temperature; (5)
- (iv) the volume compression ratio. (3)

Note: For air, $\gamma = 1.4$ and $c_p = 1.005 \text{ kJ/kg K}$.

[OVER]

3. A hydrocarbon fuel is burned in air and the volumetric analysis of the dry combustion products is: CO₂: 13.73 %; CO: 0.72%; O₂: 3.98%; N₂: 81.57%. The total pressure of the products is 1.01 bar and the dew point temperature is 57.8°C.

Calculate EACH of the following:

(a) the mass analysis of the fuel; (10)

(b) the percentage excess air supplied. (6)

Note: atomic mass relationships: H = 1; C = 12; O = 16; N = 14

Air contains 21% oxygen by volume.

4. In a regenerative steam power plant, steam enters the turbine at a pressure of 50 bar and a temperature of 400°C. It expands to 0.10 bar with an isentropic efficiency of 84%. Some steam is bled from the turbine at a pressure of 2.5 bar and supplied to a surface feed heater, from which the drain is throttled and returned to the main condenser. There is no undercooling in the condenser, and the feed water leaves the feed heater at the saturation temperature of the bled steam.

(a) Sketch a line diagram of the plant. (3)

(b) On Worksheet Q4, plot the expansion process. To estimate the bled steam condition, it may be assumed that the process line on the h-s chart is straight. (5)

(c) Estimate the thermal efficiency of the cycle. The work required to drive the feed pump may be disregarded. (8)

5. The total throat area of the nozzles of a simple impulse turbine is 2000 mm^2 . The nozzles are convergent/divergent in form, and flow is choked. Steam enters the nozzles at a pressure of 20 bar and a temperature of 450°C , and expands isentropically according to the law $p v^{1.3} = \text{constant}$ to a pressure of 8 bar. The mean blade ring diameter is 0.8 m and the speed of rotation is 6900 rev/min. The nozzle angle is 20° . The steam leaves the blades in an axial direction.

Determine EACH of the following:

$$(a) \text{ the mass flow rate of steam; } \quad (5)$$

$$(b) \text{ the blade power; } \quad (6)$$

$$(c) \text{ the blade inlet angle; } \quad (3)$$

$$(d) \text{ the diagram efficiency. } \quad (2)$$

$$\text{Note: } p_c = p_0 \times \left(\frac{2}{n+1} \right)^{n/(n-1)} ; \quad v_c = v_0 \times \left(\frac{n+1}{2} \right)^{1/(n-1)} ; \quad a = \sqrt{npv}$$

Approximate relations for the isentropic expansion of steam, given in the Steam Tables, may be used as appropriate.

6. A vapour compression refrigeration cycle uses ammonia (R717) and operates between pressures of 2.680 bar and 16.42 bar. The refrigerant enters the compressor as dry saturated vapour and is compressed with an isentropic efficiency of 85%. The temperature at outlet from the condenser is 38°C .

$$(a) \text{ Sketch the cycle on p-h and T-s diagrams. } \quad (6)$$

(b) Determine EACH of the following:

$$(i) \text{ the temperature leaving the compressor; } \quad (7)$$

$$(ii) \text{ the coefficient of performance of the cycle. } \quad (3)$$

7. A furnace wall consists of firebrick 400 mm thick. The surface heat transfer coefficients on the hot side and the cold side are $8 \text{ W/m}^2 \text{ K}$ and $6 \text{ W/m}^2 \text{ K}$ respectively. The hot gas temperature is 1300°C and the surrounding air is at a temperature of 20°C . The thermal conductivity of firebrick is 1.5 W/m K . To reduce heat loss, it is proposed that an outer layer of insulating brick of thermal conductivity 0.40 W/m K be added, but the temperature of the insulating brick must not exceed 800°C .

Calculate EACH of the following:

- (a) the rate of heat loss (per m^2) without insulation; (5)
- (b) the outside surface temperature without insulation; (3)
- (c) the maximum permissible thickness of insulating brick; (5)
- (d) the corresponding percentage reduction in heat loss. (3)

8. The free air capacity of a reciprocating air compressor is $15 \text{ m}^3/\text{min}$. Free air and suction pressure and temperature are 0.98 bar and 27°C respectively. The delivery pressure is 13.0 bar . Compression is carried out in two stages with perfect intercooling. The stage pressure ratios are equal. The index of compression and expansion is 1.30 .

- (a) Sketch the p-V diagram for the compressor. (3)
- (b) Calculate EACH of the following:
 - (i) the total indicated power; (7)
 - (ii) the rate of intercooling; (2)
 - (iii) the isothermal efficiency. (4)

Note: For air, $R = 0.287 \text{ kJ/kg K}$ and $c_p = 1.005 \text{ kJ/kg K}$.

9. Air enters the compressor of a gas turbine plant at a temperature of 30°C and leaves at a temperature of 300°C . It then enters the combustion chamber, from which hot gas leaves at a pressure of 7.0 bar and a temperature of 1200°C . The hot gas then enters the turbine and expands to a pressure of 1.15 bar with isentropic efficiency 82%. The turbine exhaust passes to a heat exchanger where heat is transferred to evaporating steam. The gas leaves the heat exchanger at a temperature of 350°C . Saturated water enters the heat exchanger at a pressure of 44 bar, and steam leaves with a dryness fraction of 0.92. The effective surface area for heat transfer is 20 m^2 , and the overall U-value is $1800 \text{ W/m}^2 \text{ K}$.

Determine EACH of the following:

- (a) the rate of heat transfer in the heat exchanger; (6)
- (b) the mass flow rate of steam; (3)
- (c) the gross power output of the turbine; (5)
- (d) the net power output of the plant. (2)

*Note: For air, $c_p = 1.005 \text{ kJ/kg K}$
For hot gas, $c_p = 1.15 \text{ kJ/kg K}$ and $\gamma = 1.35$*

(This worksheet must be returned with your answer book)

Enthalpy Entropy Chart for Steam

(prepared at Glasgow College of Nautical Studies using data from NEL Steam Tables 1964 and other formulations: for exercises only)

