**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, 18 JULY 2011**

**1315 - 1615 hrs**

Examination paper inserts:

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| 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 bar and a temperature of 300 K is compressed polytropically in an engine cylinder from a volume of 0.4 $m^3$ to a volume of 0.03 $m^3$. The pressure after compression is 48.7 bar. Heat is then supplied at constant pressure until the temperature is 1800 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 $R = 0.287$ kJ/kg K.*

2. In an air standard Diesel cycle the volume at the end of heat supply is 1.96 times that at the beginning of heat supply. The temperature at the beginning of compression is 303 K, and that at the end of expansion is 777 K. The thermal efficiency is 66.8%.

   (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 $c_P = 1.005$ kJ/kg K.*

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3. A hydrocarbon fuel is burned in air and the volumetric analysis of the dry combustion products is: $CO_2$: 10.11 %; CO: 1.68%; $O_2$: 4.55%; $N_2$: 83.66%. The total pressure of the products is 1.01 bar and the dew point temperature is 49.4°C.

Determine 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 70 bar and a temperature of 580°C. It expands to 0.05 bar with an isentropic efficiency of 80%. Some steam is bled from the turbine at a pressure of 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 3000 $mm^2$. The nozzles are convergent/divergent in form, and flow is choked. Steam enters the nozzles at a pressure of 10 bar and a temperature of 400°C, and expands isentropically according to the law $pv^{1.3}$ = constant. The mean blade ring diameter is 1 m and the speed of rotation is 9365 rev/min. The blades are symmetrical with a blade angle of 36°. The blade velocity coefficient is 1, and steam leaves the blades in an axial direction.

Determine EACH of the following:

(a) the mass flow rate of steam; (5)

(b) the blade power; (4)

(c) the nozzle angle; (3)

(d) the nozzle exit pressure. (4)

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

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

6. A vapour compression refrigeration cycle uses ammonia (R717) and operates between pressures of 2.908 bar and 15.54 bar. The refrigerant enters the compressor as dry saturated vapour and is compressed with an isentropic efficiency of 80%. The temperature at outlet from the condenser is 36°C.

(a) Sketch the cycle on p-h and T-s diagrams. (6)

(b) Determine EACH of the following:

(i) the temperature leaving the compressor; (7)

(ii) the coefficient of performance of the cycle. (3)

7. A furnace wall consists of firebrick 440 mm thick. The surface heat transfer coefficients on the hot side and the cold side are 10 $W/m^2$ K and 5 $W/m^2$ K respectively. The hot gas temperature is 1500°C and the surrounding air is at a temperature of 25°C. The thermal conductivity of firebrick is 1.6 W/m K. To reduce heat loss, it is proposed that an outer layer of insulating brick of thermal conductivity 0.45 W/m K be added, but the temperature of the insulating brick must not exceed 850°C.

Determine 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 12 $m^3$/min. Free air and suction pressure and temperature are 1.02 bar and 32°C respectively. The delivery pressure is 12.0 bar. Compression is carried out in two stages with perfect intercooling. The stage pressure ratios are equal. The index of compression and expansion is 1.27.

(a) Sketch the p-V diagram for the compressor. (3)

(b) Determine 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 kJ/kg K and* $c_P$ *= 1.005 kJ/kg K.*

9. Air enters the compressor of a gas turbine plant at a temperature of 27°C and leaves at a temperature of 280°C. It then enters the combustion chamber, from which hot gas leaves at a pressure of 6.5 bar and a temperature of 1100°C. The hot gas then enters the turbine and expands to a pressure of 1.02 bar with isentropic efficiency 85%. 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 400°C. The steam enters as saturated liquid at a pressure of 28 bar, and leaves with a dryness fraction of 0.98. The effective surface area for heat transfer is 18 $m^2$, and the overall U-value is 2000 $W/m^2$ K.

Determine EACH of the following:

(a) the rate of heat transfer in the heat exchanger; (6)

(b) the mass flow rate of steam; (2)

(c) the gross power output of the turbine; (3)

(d) the overall thermal efficiency of the plant (including the heat transferred to the steam as part of the useful output). (5)

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

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