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, 12 JULY 2021

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

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1. A volume of 0.06 m^3 of ethane is at a pressure and temperature of 6.9 bar and 260°C respectively.

   It expands in an isentropic process to a pressure of 1.05 bar after which, it is compressed to a final pressure of 6.9 bar according to the law $PV^{1.4}$ = constant.

   The overall change of entropy for the processes is 232.3 J/kgK.

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

   (b) Calculate EACH of the following:

   (i) the final temperature of the ethane; (3)

   (ii) the volume at the cardinal points; (3)

   (iii) the net work transfer; (4)

   (iv) the net heat transfer. (4)

   Note: for Ethane, Molecular mass M = 30 kg/kmol, γ=1.219, c_p = 1.542 kJ/kgK
   Universal gas constant R_o = 8.3145 kJ/kmolK

2. In an ideal dual combustion cycle, the maximum and minimum pressures are 60 bar and 1 bar respectively.

The volume compression ratio is 16:1 and the minimum temperature is 17°C.

The cycle mean effective pressure is 10 bar and the air standard efficiency is 60%.

(a) Sketch the cycle on Pressure-volume and Temperature-specific entropy diagrams. (2)

(b) Calculate EACH of the following for 1 kg of air:

(i) the total heat supplied; (4)

(ii) the maximum cycle temperature; (6)

(iii) the volume of constant pressure heat addition as a percentage of the stroke. (4)

Note: for air c_v *= 0.718 kJ/kgK,* c_p *= 1.005 kJ/kgK* $\gamma = 1.4$

3. A gaseous fuel contains 60% ethane (C_2H_6) and 40% methane (CH_4) by volume and is completely burned with 10% excess air by volume.

The combustion products are at a pressure and temperature of 4.756 bar and 500°C respectively and are cooled at constant pressure to 100°C.

At these conditions the dew point temperature of the products was calculated to be 91.8°C.

Calculate EACH of the following for one kmol of fuel:

(a) the equation of combustion by volume; (8)

(b) the mean specific heat at constant pressure for the dry gas; (4)

(c) the total quantity of heat removed from the gas. (4)

Note: *atomic mass relationships H = 1, C = 12, O = 16, N = 14.*
Air contains 21% oxygen by volume.
for O_2 $c_p = 1.042$ *kJ/kgK*
for CO_2 $c_p = 1.148$ *kJ/kgK*
for N_2 $c_p = 1.11$ *kJ/kgK.*

4. A rigid vessel has a volume of 0.5 m^3 and contains air at 0.7 bar and 75°C.

1.2 kg of fresh water is injected into the vessel during which time the temperature remains constant.

The vessel is then heated for 10 minutes at which point all the water has just evaporated.

Calculate EACH of the following;

(a) the total pressure of the vessel at the end of the water injection; (5)

(b) the total pressure and temperature of the vessel at the end of heating; (3)

(c) the rate at the heat is supplied. (8)

Note: for air c_v= 0.718 kJ/kgK, R = 0.287 kJ/kgK

5. The first stage of an impulse turbine is velocity compounded with two rows of moving blades.

The isentropic specific enthalpy drop in the nozzle is 355.6 kJ/kg and the isentropic efficiency is 90%.

The steam leaves the nozzles at an angle of 22° to the plane of rotation and the mean blade speed is 150 m/s.

The moving blade angles are designed to give zero axial thrust and the fixed blade angles are symmetrical.

The velocity coefficient is 0.9 for all the blades.

(a) Calculate the velocity of the steam leaving the nozzle. (2)

(b) Draw the velocity vector diagrams to a scale of 1 mm = 5 m/s. (4)

(c) Using the vector diagram state EACH of the following:

(i) the absolute and relative steam velocities; (2)

(ii) the fixed and moving blade angles. (2)

(d) Calculate EACH of the following for 1 kg of steam:

(i) the driving force on the wheel; (2)

(ii) the specific power output; (2)

(iii) the diagram efficiency. (2)

6. A vapour compression refrigeration plant is used to cool 12000 litres per hour of a fluid from 27°C to 4°C.

Heat leakage into the plant is estimated as 3600 kJ/min.

The refrigerant is ammonia and the evaporator temperature must remain constant at -6°C.

The compressor discharge pressure and temperature are 10.34 bar and 101°C respectively. The liquid leaves the condenser with 6 K of undercooling.

The compressor has 4 cylinders each with a swept volume of $6.219 \times 10^{-3}\ m^3$ and a volumetric efficiency of 85% at the operating conditions.

(a) Sketch the cycle on Pressure-specific enthalpy and Temperature-specific entropy diagrams indicating reversible and irreversible processes. (4)

(b) Calculate EACH of the following:

(i) the compressor power; (6)

(ii) the coefficient of performance; (2)

(iii) the speed of the compressor. (4)

Note: for the fluid, specific heat capacity $c = 3.77$ *kJ/kgK,* $\rho = 1030\ kg/m^3$

7. A steel pipeline is 100 m long, has an internal diameter of 250 mm, a wall thickness of 15 mm and is coated with a single layer of insulation.

Dry saturated steam at 30 bar enters the pipe at the rate of 750 kg/hr and leaves the pipe with a dryness fraction of 0.95. The outer surface temperature of the insulation is 25°C.

A further layer of the same insulation is added, increasing the original thickness by 15% while maintaining the outer surface temperature at 25°C.

Calculate EACH of the following:

(a) the outer diameter of the original layer of insulation; (6)

(b) the percentage reduction in heat transfer due to the additional insulation; (6)

(c) the rate of steam condensation in the final insulated condition. (4)

Note: inner surface heat transfer coefficient = 20 W/m^2K
thermal conductivity of steel = 50 W/mK
thermal conductivity of insulation = 0.09 W/mK

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

It delivers 278 m^3/hour at a free air pressure and temperature of 1.013 bar and 0°C respectively.

The inlet pressure and temperature are 1 bar and 15°C respectively. The delivery pressure is 25 bar and the clearance ratio is 0.04.

The polytropic index of compression and expansion in both stages is 1.3.

The low-pressure cylinder bore is 350 mm and the compressor speed is 360 rev/min.

(a) Sketch the cycle on a Pressure-volume diagram. (2)

(b) Calculate EACH of the following;

(i) the indicated power; (4)

(ii) the rate of heat removal in the intercooler; (4)

(iii) the low-pressure cylinder bump clearance. (6)

Note: For air $R = 287\ J/kgK$, $\gamma = 1.4$

9. A centrifugal pump runs at 800 rev/min and discharges sea water at the rate of 10 m^3/min against a head of 9 m.

The impeller has an outer diameter of 300 mm and a width at exit of 100 mm.

The vanes are backward facing at an angle of 40° to the impeller tangent.

There is no whirl at inlet and the vane thickness may be ignored.

(a) Sketch the exit velocity vector diagram indicating all the velocities. (4)

(b) Calculate EACH of the following:

(i) the radial velocity of the fluid; (2)

(ii) the whirl velocity at exit; (3)

(iii) the absolute velocity at exit; (2)

(iv) the theoretical head; (3)

(v) the manometric efficiency. (2)