9210-128
Level 6 Graduate Diploma in Engineering
Applied thermodynamics

Sample Paper

You should have the following for this examination
- answer booklets
- drawing instruments
- non-programmable calculator
- pen, pencil, ruler

You will be provided with the following documents for this examination
- Table of thermodynamic and transport properties of fluids (steam tables)
- Mollier diagram (h-s Chart)
- Psychrometric Chart

General instructions
- This examination paper is of **three hours** duration.
- This paper contains **nine** questions.
- Answer **five** questions.
- All pressures are absolute unless otherwise stated.
- Take following air properties
  Specific heat capacities **c_p = 1.005 kJ/kgK** and **c_v = 0.718 kJ/kgK**
  Ratio of heat capacities **y = 1.4**
  Characteristic gas constant **R = 0.287 kJ/kgK**
  Universal gas constant **R = 8.314 J/mol**.
- All questions carry equal marks. The maximum marks for each section within a question are given against that section.
- An electronic, non-programmable calculator may be used but candidates **must** show clearly the steps prior to obtaining final numerical values.
- Drawings should be clear, in good proportion and in pencil. Do **not** use red ink.

1 a) Explain briefly the air- standard Otto cycle with the aid of a P-V diagram. (4 marks)

b) The temperature and the pressure at the beginning of the compression process of an air standard Otto cycle is 290 K and 1 bar respectively. The cylinder volume is 400 cm^3. The compression ratio is 8. The maximum temperature of the cycle is 2200 K.

Determine the following.

i) Heat addition in kJ. (4 marks)

ii) Net work in kJ. (4 marks)

iii) Cycle efficiency. (4 marks)

iv) Mean effective pressure in bar. (4 marks)

2 a) Sketch the indicator diagram for an ideal single-acting single-stage reciprocating compressor and show that the volumetric efficiency (η_{vol}) is given by,

$$\eta_{vol} = 1 - \frac{V_c}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right]$$

where ,

- V_c – Clearance volume.
- V_s – Swept volume.
- P_2/P_1 – Pressure ratio.
- n – Index of compression and expansion. (6 marks)

b) Inlet air temperature and pressure of a single-acting, single cylinder air compressor running at 340 rev/min is 25 °C and 1 bar respectively. The air compressor is driven by a 25 kW electric motor. The cylinder bore is equal to the stroke. The delivery pressure is 9 bar and the clearance volume is 7% of swept volume.

Index of compression and expansion is 1.3 and mechanical efficiency of the drive between motor and compressor is 85%.

Calculate the following.

i) Mass flow rate of air. (2 marks)

ii) Free air delivery. (4 marks)

iii) Volumetric efficiency. (4 marks)

iv) Stroke length. (4 marks)

3 a) Define the following terms.

i) Dry-bulb temperature. (2 marks)

ii) Wet-bulb temperature. (2 marks)

b) Can the dry-bulb and wet-bulb temperatures be equal? Explain your answer. (4 marks)

c) Water exiting the condenser of a power plant at 38°C enters a cooling tower with a mass flow rate of 4.5 x 10^7 kg/h. A stream of cooled water at 30°C is returned to the condenser from the cooling tower with the same flow rate. Makeup water is added in a separate stream at 20°C. Atmospheric air enters the cooling tower at 25°C and 35% relative humidity. Moist air exits the tower at 30°C and 90% relative humidity. The cooling tower operates at steady state. The pressure remains constant throughout at 1 atm.

Determine the following.

i) Mass flow rates of the dry air. (8 marks)

ii) Makeup water, in kg/h. (4 marks)

4 a) Briefly explain the following terms.

- i) Brake power. (2 marks)
- ii) Indicated thermal efficiency. (2 marks)

b) Explain the phenomenon of **detonation** in a spark ignition internal combustion engine. (4 marks)

c) A four-stroke spark ignition engine was tested on a standard test bench and the following results were observed.

Engine Speed	2500 rpm
Number of cylinders	4
Bore of cylinder	110 mm
Cylinder Stroke	70 mm
Rate of fuel consumption	0.16 kg per minute
Torque	100 Nm
Area of indicator diagram	740 mm^2
Base length of indicator diagram	60 mm
Pressure scale	50 kPa/mm

Calorific value of fuel is given as 45 MJ/kg. Calculate the following.

- i) Brake power. (2 marks)
- ii) Indicated power. (5 marks)
- iii) Brake thermal efficiency. (3 marks)
- iv) Mechanical efficiency. (2 marks)

5 a) Is the Carnot vapour power cycle a suitable model for the analysis of a simple vapour power plant? Justify your answer. (5 marks)

b) As shown in Figure Q5, steam at 10 MPa and 600°C enters the first-stage of a turbine of a power plant that operates on the Rankine cycle with reheat. The steam leaving the reheat section of the steam generator is at 500°C. The condenser pressure is 6 kPa. The quality of steam at the exit of the second stage of the turbine is 90% dry.

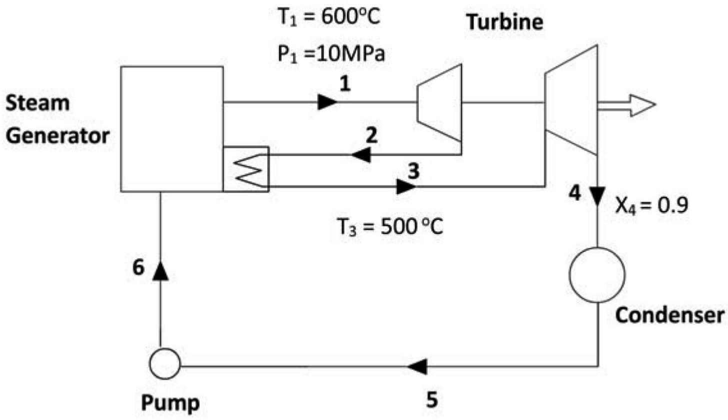

Figure Q5

- i) Show the thermodynamic cycle on a temperature-entropy diagram with given data. (3 marks)
- ii) Find the reheat pressure. (6 marks)
- iii Determine the thermal efficiency of the cycle. (saturated liquid enthalpy of steam at 6 kPa is 151.33 kJ/kg) (6 marks)

6 A vapour-compression refrigeration plant uses carbon dioxide as the refrigerant. The condensation temperature is 20°C and the evaporator temperature is 10°C. Temperature after isentropic compression is 40°C and condensate leaves at 10°C before being passed through the expansion valve. Refrigerating effect of 2 kW is desired from the cycle.
Properties of carbon dioxide are given below in Table Q6.
Determine the following.

a) Mass flow rate of carbon dioxide. (14 marks)
b) Coefficient of Performance (COP) of the system. (6 marks)

Temp. °C	Saturation pressure (bar)	Specific volume (m^3/kg)	Enthalpy kJ/kg		Entropy kJ/kgK		Specific heat kJ/kgK	
			hf	hg	sf	sg	C_{pf}	C_{pg}
20	57.3	–	144.1	299.6	0.52	1.05	2.89	2.13
–10	26.5	0.014	60.8	322.3	0.24	1.23	–	–

Table Q6

7 In a regenerative two-shaft gas turbine power plant, air enters the compressor at 1 bar and 27°C with a mass flow rate of 0.562 kg/s and is compressed to 4 bar. The isentropic efficiency of the compressor is 80%, and the regenerator effectiveness is 90%. All the power developed by the high-pressure turbine is used to run the compressor. The low-pressure turbine provides the net power output. The temperature at the inlet to the high-pressure turbine is 1200 K. Assume that turbines are 100% efficient.
Determine the following.

a) Net power output, in kW. (14 marks)
b) Thermal efficiency.
(take specific heat ratio (γ) for air as 1.4 and for combustion gas γ as 1.33) (6 marks)

8 In an impulse turbine, the mean diameter of the blade rotor is 105 cm and it has a speed of 3000 rev/min. The nozzle angle is 18°, the ratio of blade sped to steam speed is 0.42 and the ratio of the relative velocity at outlet from the blades to that at inlet is 0.84. The outlet angle of the blade is to be made 3° less than the inlet angle.
The steam flow rate is 8 kg/s.

a) Draw the velocity diagram for the blades indicating velocity components. (4 marks)
b) Find suitable blade angles. (4 marks)
c) Calculate axial thrust and tangential thrust. (6 marks)
d) Calculate power developed in blading. (3 marks)
e) Estimate the blading efficiency. (3 marks)

9 a) How should the shape of a nozzle and a diffuser vary according to the value of the Mach number that determines the flow regime? (6 marks)

b) Air in a reservoir has a temperature of 27°C and a pressure of 0.8 MPa. The air is allowed to escape through a channel at a rate of 2.5 kg/s. Assuming that the air velocity in the reservoir is negligible and the flow is isentropic, determine the following at a section in the channel where the static pressure is 0.6 MPa.

i) Mach number. (4 marks)
ii) Velocity at the section. (5 marks)
iii) Area of the section. (5 marks)

You may use following equations

$$\frac{P_o}{P} = \left[1 + \left(\frac{\gamma - 1}{2}\right) M^2\right]^{\frac{\gamma}{\gamma - 1}} \qquad \frac{T_o}{T} = 1 + \left(\frac{\gamma - 1}{2}\right) M^2$$

Where, Subscript ‘0’ refers to inlet conditions.