Sample Question Paper for 9210-128
Graduate Diploma in Mechanical Engineering
Applied thermodynamics

Duration: three hours

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

The following data is attached
- Mollier diagram

General instructions
- This paper consists of **nine** questions.
- Answer any **five** questions.
- A non-programmable electronic calculator may be used but candidates **must** show sufficient steps to justify their answers.
- Drawings should be clear, in good proportion and in pencil. Do not use red ink.
- All questions carry equal marks. The maximum marks for each section within a question are shown.
- All pressures are absolute unless otherwise stated.
- Take specific heat capacities of air c_p = 1.005 kJ/kg K & c_v = 0.718 kJ/kg K
  Universal gas constant R = 8.314 kJ/kmol K.
- Use 'Table of thermodynamic and transport properties of fluids (steam tables)'.

1 a) Explain briefly the air-standard Diesel cycle with the aid of a P-V diagram. (3 marks)

b) Derive an expression for the ideal cycle efficiency of an air-standard Diesel cycle relating compression ratio and cut-off ratio and using the usual notations. (5 marks)

c) In an air-standard Diesel cycle, initially air is taken in with a temperature of 15 °C and a pressure of 0.1 MPa. The volumetric compression ratio for the cycle is 18 and heat added per cycle is 1800 kJ/kg.

Determine,

i) the temperatures and pressures at the end of each process of the cycle (6 marks)

ii) the ideal cycle efficiency (2 marks)

iii) the mean effective pressure. (4 marks)

2 a) Explain briefly with the aid of a P-V diagram the effect of inter-cooling on the performance of a two-stage reciprocating air compressor. (3 marks)

b) Derive an expression for the optimum intermediate pressure of a two-stage reciprocating air compressor when inter-cooling is complete between the stages. Use the usual notations. (5 marks)

c) A single acting two-stage air compressor delivers 8 kg per minute of compressed air at a pressure of 25 bars. The air inlet pressure and temperature are 1 bar & 18 °C respectively and the compressor runs at 300 rpm. Compression and expansion processes are carried out reversibly and polytropically with a polytropic index of 1.3. There is an intercooler between the stages which performs complete inter-cooling of the air.

Calculate,

i) the power required by the compressor (3 marks)

ii) the free air delivered and the exit air temperature (3 marks)

iii) the net heat transferred in each cylinder and in the intercooler. (6 marks)

3 a) Define the following terms.

i) Moisture content. (2 marks)

ii) Relative humidity. (2 marks)

iii) Dew point. (2 marks)

b) Derive an expression for the moisture content of humid air in terms of partial pressures of the constituents and using the usual notations. (4 marks)

c) Water is supplied to a cooling tower at 45 °C and sprayed downwards into the rising column of air. Atmospheric air enters the base of the tower at a rate of 540 m^3 per minute with a pressure of 1 bar, a temperature of 15 °C and a relative humidity of 60 %. The air is returned to the atmosphere from the top of the cooling tower with a temperature of 25 °C and in a saturated condition. The mass flow rate of water entering the tower is 250 kg per minute.

Calculate,

i) the rate at which make-up water must be supplied to replace the quantity of water evaporated (6 marks)

ii) the temperature of the water leaving the cooling tower. (4 marks)

4 a) Explain briefly the following terms when applied to an internal combustion engine.

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 bed and the results in Table Q4 were observed.

#	Parameter	Value
1	Engine Speed	2400 rpm
2	Number of cylinders	4
3	Bore of cylinder	100 mm
4	Stroke	80 mm
5	Rate of fuel consumption	0.15 kg per minute
6	Calorific value of fuel	45 MJ/kg
7	Torque	100 Nm
8	Area of indicator diagram	720 mm^2
9	Base length of indicator diagram	60 mm
10	Pressure scale	50 kPa/mm

Table Q4

Calculate the following performance values for the test.

i) Brake power. (2 marks)

ii) Indicated power. (5 marks)

iii) Brake thermal efficiency. (3 marks)

iv) Mechanical efficiency. (2 marks)

5 a) Explain the concept of regeneration that can be used to improve the thermal efficiency of a steam power plant. (6 marks)

b) A hypothetical steam power plant has a single open - type feed water heater. Steam leaves the boiler at a pressure of 10 bar and temperature of 400 °C. The pressure in the condenser is 0.035 bar. Expansion in the turbine is reversible and adiabatic. The feed water heater takes steam bled from the turbine at a pressure of 0.7 bar where the steam is in a saturated state. Neglect feed pump work.

i) Illustrate the cycle in a temperature-entropy diagram. (2 marks)

ii) Calculate the mass of steam bled from the turbine per kilogram of steam leaving the boiler. (6 marks)

iii) Calculate the thermal efficiency of the cycle. (4 marks)

iv) Determine the percentage improvement of thermal efficiency when compared to that of a Rankine cycle. (2 marks)

6 a) Explain the effect of sub-cooling on a vapour compression refrigeration cycle with the aid of a temperature-entropy diagram. (4 marks)

b) In a vapour-compression refrigeration cycle the evaporator and condenser temperatures are -14 °C and 40 °C respectively. The refrigerant enters the compressor as dry saturated vapour. The refrigerant leaving the condenser has a temperature of 30 °C.
Data for the refrigerant are given in Table Q6.
Refrigerant properties:

Temperature (°C)	**Enthalpy (kJ/kg)**		**Entropy (kJ/kgK)**	
	Liquid	Vapour	Liquid	Vapour
-14	187.14	346.32	0.9520	1.5662
40	239.03	368.81	1.1315	1.5459

Table Q6

Specific heat capacity at constant pressure;
for superheated vapour – 0.762 kJ/kgK
for liquid – 1.03 kJ/kgK

Calculate,

i) refrigerating effect (4 marks)

ii) compressor work (4 marks)

iii) mass flow rate needed for 1 ton of refrigeration capacity (1 TR).
Note: 1 TR capacity is equivalent to 3.5 kJ/s in SI units. (4 marks)

iv) coefficient of performance (COP) of the cycle. (4 marks)

7 a) i) State three important modifications that could be made to a simple gas turbine plant to improve performance. (3 marks)

ii) Briefly explain the effects of these modifications on the performance of the gas turbine plant. (6 marks)

b) In a gas turbine plant compression is carried out in two stages with perfect inter-cooling between the stages. Expansion takes place in one stage. Derive an expression for the net work output of the cycle in terms of maximum temperature (T_{max}) and minimum temperature (T_{min}). Hence show that the optimum overall pressure ratio ($r_{optimum}$) for maximum work output of the plant is given by:

$$r_{optimum} = \left[\eta_T \eta_C \frac{T_{\max}}{T_{\min}} \right]^{\frac{2\gamma}{3(\gamma - 1)}}$$

γ – Adiabatic index
η_T – Isentropic efficiency of the turbine
η_C – Isentropic efficiency of the compressor. (11 marks)

8 a) Identify the difference between a simple impulse turbine and a reaction turbine. (4 marks)

b) Define the following terms in relation to a steam turbine.

i) Speed ratio. (2 marks)

ii) Diagram efficiency. (2 marks)

iii) Blade velocity coefficient. (2 marks)

c) In an impulse turbine (with a single row wheel) the mean diameter of the rotor is 0.8 m and its speed is 2800 rpm. The nozzle angle is 18° and the ratio of blade speed to steam speed is 0.4. The ratio of relative velocity at outlet from the blades to that at inlet is 0.85. The outlet angle of the blade is 4° less than the inlet angle. The steam flow rate is 8 kg/s.

i) Draw the velocity diagram for the blades. (4 marks)

ii) Calculate the tangential thrust and the axial thrust on the blades. (4 marks)

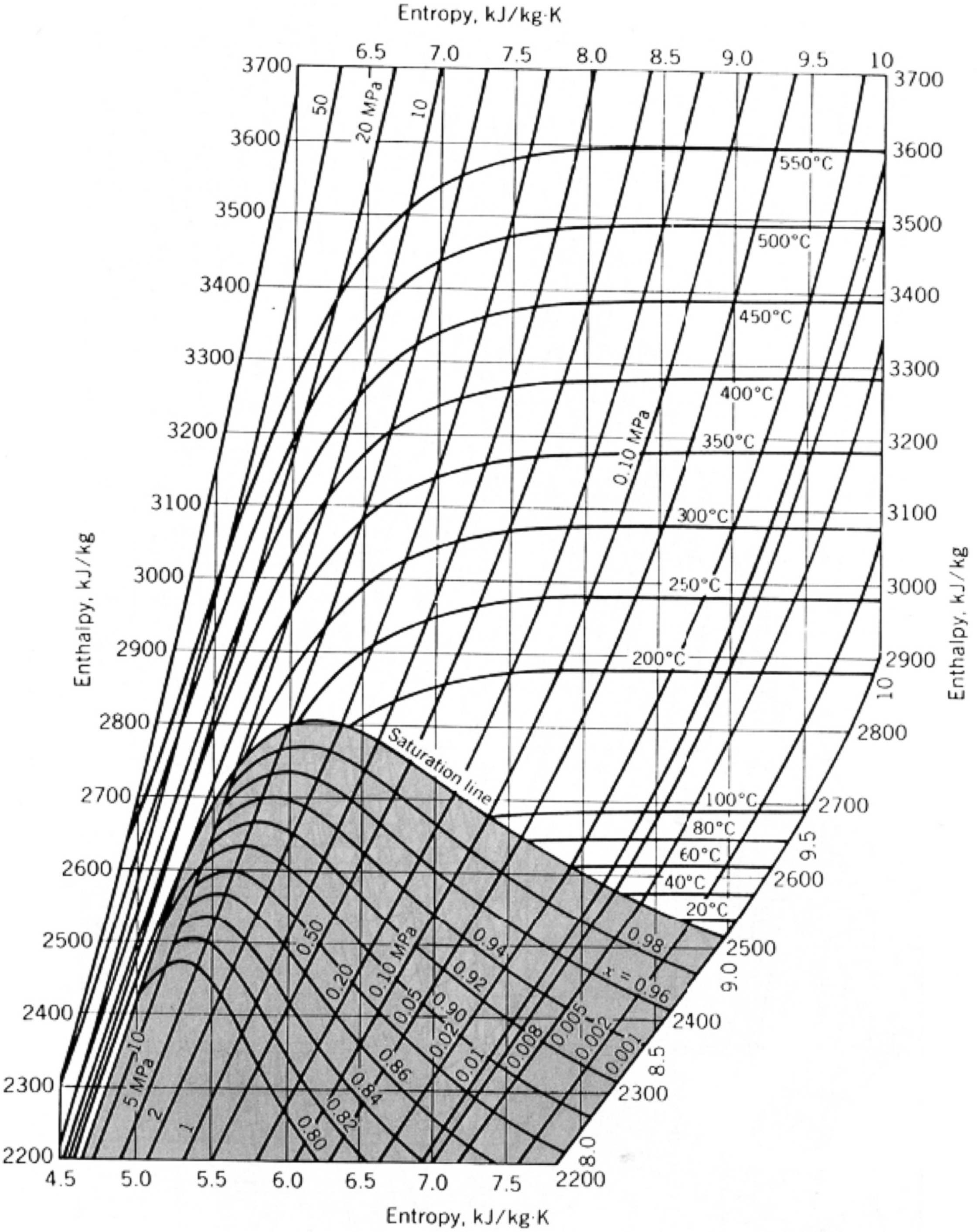
iii) Calculate the diagram efficiency. (2 marks)

9 a) Explain the term critical pressure as applied to steam nozzles. (2 marks)

b) Dry saturated steam at a pressure of 12 bar flows through a convergent nozzle of throat area of 0.6 cm^2. The pressure at the throat is 7.0 bar. The flow is isentropic and in thermal equilibrium.
Determine the exit velocity and the discharge. (18 marks)

Data Attachments

Mollier Chart - Metric



Enthalpy-entropy diagram for water (SI units). *Source*: J. B. Jones and G. A. Hawkins, *Engineering Thermodynamics*, 2nd ed., Wiley, New York, 1986.