MACHAKOS UNIVERSITY

University Examinations 2023/2024 Academic Year

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

EMM 404: THERMODYNAMICS III

Time: 2 Hours

Instructions:

- This paper consists of **FIVE** questions
- Attempt **Question 1** and any other **TWO** questions
- Maximum marks for each part of a question are as indicated.

Provided

- Molar (Universal) gas constant R_O = 8314.5 J/kmolK
- Thermodynamic and Transport Properties of Fluids, SI Units - by Rogers G.F.C and Mayhew Y.R

Question 1(30 marks)

a) Consider the specific entropy, s, for a homogeneous substance to be a function of specific volume, v, and temperature, T. Then with the help of the Maxwell relations and the expression for specific enthalpy, show that the Clapeyron equation characterizing the phase transition between two phases of matter is expressed as:

$$\frac{dP}{dT} = \frac{L}{T\,\Delta v}$$

Where, $\frac{dP}{dT}$ - is the slope of the coexistence curve; L – is the latent heat;

T – is the temperature; Δv - is the volume change of the phase transition. *[5 marks]*

b) Show that the volumetric efficiency of a compressor with clearance volume V_c and stroke volume V_s, is given by the expression:

$$\eta_v = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right\}$$

Where P_1 and P_2 are the induction and delivery pressures respectively, while n is the polytropic index of compression/expansion. *[5 marks]*

c) For steam at 600 kPa and 300 °C, verify the Maxwell relation; *[5 marks]*

$$\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P$$

d) Briefly explain the term 'Metastable flow' in nozzles. Hence outline four effects of metastable flow on steam flowing in a nozzle. *[5 marks]*

e) With the aid of an hypothetical indicator diagram for a steam engine without considering clearance and compression obtain an expression for the hypothetical mean effective pressure. *[5 marks]*

f) Steam at a pressure of 12 bar is admitted into a steam engine and then expands hyperbolically up to a pressure of 1.6 bar. The exhaust pressure is 1.1 bar. Find the actual mean effective pressure neglecting clearance and compression and assuming diagram factor as 0.85. *[5 marks]*

Question 2 (20 marks)

a) Derive the four Maxwell relations. *[12 marks]*

b) Using the Maxwell relations and the ideal-gas equation of state, show that

$$\left(\frac{\partial S}{\partial V}\right)_T = \frac{P}{T}$$ for an ideal gas. *[3 marks]*

c) With the help of the Maxwell relations and the ideal-gas equation, prove that the internal energy of an ideal-gas is a function of temperature only. *[5 marks]*

Question 3 (20 marks)

a) List three benefits of multistage compression. *[3marks]*

b) In a single-acting, two-stage reciprocating air compressor 5 kg of air per minute are compressed from 1.0125 bar and 20 °C through a pressure ratio of 12 to 1. Both stages have the same pressure ratio, and the law of compression and expansion in both stages is $pv^{1.25}$ = constant. If intercooling is complete, assuming that the clearance volumes of both stages are 6% of their respective swept volumes and the compressor runs at 450 rev/min;

i) Present this information on a p-v diagram. *[3marks]*

ii) Calculate the indicated power required. *[5 marks]*
iii) Calculate the swept volume in each cylinder. *[9 marks]*

Question 4 (20 marks)

a) Show that for a perfect gas the critical velocity at the throat of a convergent-divergent nozzle when the pressure ratio across the nozzle is critical is written as follows.

$$C_c = \sqrt{\gamma R T_c}$$

Where the terms; γ, R, and T_c have their usual meaning. *[12 marks]*

b) A convergent divergent nozzle receives steam at 9 bar and 250°C and it expands it isentropically into a space of 3 bar. Neglecting the inlet velocity calculate the exit area required for a mass flow of 0.15 kg/sec when;

i. the flow is in equilibrium through all;

ii. the flow is supersaturated with $pv^{1.3}$ = constant *[8 marks]*

Question 5 (20 marks)

A single stage impulse steam turbine has mean blade speed of 170 m/s; steam leaves nozzle with 900 m/s velocity at angle of 18º. The exit blade angle is 25º. If blade velocity coefficient is 0.92; for a steam flow rate of 5 kg/s, determine:

i. The power output,
ii. The specific steam consumption,
iii. The diagram efficiency. *[20 marks]*