UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Chemical Eng E808: Thermodynamics

COURSE CODE	:	**CENGE808**
UNIT VALUE	:	**0.50**
DATE	:	**15-MAY-03**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

03-C0183-3-110

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Answer ***FOUR QUESTIONS.*** **Only the first four answers given will be marked.**
*ALL questions carry a total of **25 MARKS** each, distributed as shown [ ]*

R = 8.314 J / gmol K; 1 bara = 10^5 N / m^2

1.

i) Define the first law of thermodynamics for a closed system in the form of an algebraic equation, carefully explaining the symbols used. [4]

ii) What is the change in internal energy for a cyclic process. Justify your answer. [3]

iii) Explain what are meant by open, closed and isolated systems in the context of thermodynamics. [3]

iv) One kilogram of steam is contained in a constant volume container, originally at 150 °C and 3.5 bara. Heat amounting to 645 kJ is added to the steam. Using the steam tables provided, determine the final temperature, pressure and enthalpy. Also, using the defining equation for enthalpy, check the validity of your calculation for the final enthalpy. [15]

2.

i) Show that for an ideal gas undergoing an adiabatic process in a closed system:

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

where γ = ratio of specific heat capacities. [9]

ii) Find the changes in internal energy, enthalpy, heat, work and entropy for the following processes, all performed on 1 gmol of an ideal gas with $C_V = \frac{5}{2}R$:

a) a constant pressure heating from 25 °C to 100 °C [4]
b) an adiabatic reversible expansion from 200 °C, 5 bara to 1 bara [4]
c) an isothermal reversible expansion from 200 °C, 5 bara to 1 bara [4]
d) a constant volume heating from 25 °C, 1 bara to 100 °C [4]

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3.

i) Starting from first principles, derive the following Maxwell relations:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T$$

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

[12]

ii) Using an appropriate Maxwell relation, evaluate the partial derivative $(\partial S / \partial V)_T$ for steam at 240°C and specific volume, V of 0.4646 m^3/kg. You may assume that the PVT behaviour for steam may be approximated by the Redlich-Kwong equation of state given by:

$$P = \frac{RT}{V-b} - \frac{a}{V(V+b)T^{1/2}}$$

where a = 142.59 bar $(m^3/kmol)^2 K^{1/2}$ and b = 0.0211 $m^3/kmol$. Compare your result against that obtained using the steam tables provided. [13]

4.

i) Draw a simple process flow diagram for a two-stage reciprocating compressor with perfect intermediate cooling. Explain what is meant by "perfect intermediate cooling": [4]

ii) With reference to the same diagram, carefully draw the corresponding pressure/volume (P/V) behaviour for the gas being compressed. Indicate the work saved as a result of intermediate cooling in the P/V diagram. [4]

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iii) Show that the work, W required for adiabatic compression of an ideal gas from pressure P_1 to P_2 is given by

$$W = -RT\left(\frac{\gamma}{\gamma - 1}\right)\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

where, γ is the ratio of the specific heat capacities. [7]

iv) Determine the theoretical best pressure, P_2, to use as the intermediate pressure between the two stages of a reversible, adiabatic compressor; that is, the pressure which will yield the minimum work to get from P_1, the inlet, to P_3, the outlet pressure. Assume perfect intermediate cooling and ideal gas behaviour. Express your final answer in terms of P_1 and P_3. [10]

5.

Draw a simple process flow diagram for a Rankine power cycle with superheat, carefully explaining each step in the cycle. [6]

i) With reference to the same cycle, draw the corresponding T/S diagram, explaining each step. [6]

ii) In a Rankine cycle, steam leaves the boiler and enters the turbine at 40 bara and 400 °C. The condenser pressure is 1 bara. Determine the cycle efficiency. [13]

6.

Draw a simple process flow diagram for a vapour compression refrigeration cycle, carefully explaining each step in the cycle. [6]

i) With reference to the same cycle, draw the corresponding T/S diagram. [6]

CONTINUED

ii) The pressure in the evaporator of an ammonia refrigerator is 1.902 bara and the pressure in the condenser is 12.37 bara. What is the ideal (Carnot) coefficient of performance for the machine working between the corresponding temperatures, and what is the ideal refrigeration effect? Calculate the refrigeration effect per kg of the refrigerant and the COP for the practical cycle working between the same pressures when

a) dry saturated vapour is delivered to the condenser after isentropic compression, and there is no undercooling of the condensed liquid [7]

b) dry saturated vapour is delivered to the compressor where it is compressed isentropically and there is no undercooling of the condensed liquid. [6]

7.

Discuss what is meant by the second law of thermodynamics and explain two of its corollaries. Also, [4]

i) show that for any thermodynamic process to take place, there must be a net increase in its entropy. [6]

ii) what is the qualitative relationship between process efficiency and the net entropy change? Justify your answer. [3]

iii) 1 kmol of an ideal gas is compressed isothermally at 300 K from 1 bara to 10 bara in a piston and cylinder arrangement. Calculate the entropy change of the gas, the entropy change of the surroundings, and the total entropy change resulting from the process, if

a) the process is reversible and the surroundings consists of an infinite heat reservoir at 300 K [5]

b) the process is irreversible, requiring 20 % more work than the reversible compression, and the surroundings consist of a heat reservoir at 300 K. [5]

c) comment on the difference between your answers for a) and b) above. [2]

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