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	:	**18-MAY-04**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

04-C0183-3-120

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Answer **FOUR QUESTIONS** only. Each Question carries a total of **25** marks distributed as shown

1.

i) State what is meant by the term, 'State Function'. Explain if heat, work, internal energy and enthalpy are state functions. [4]

ii) 1 m^3 of gas, assumed to be ideal, is isothermally expanded from 10 bara to 5 bara.

a) Calculate the amount of work involved in expanding the gas through both reversible or irreversible paths.

b) Calculate the process efficiency if the expansion follows an irreversible path and comment on your answer.

c) State four of the criteria that need to be fulfilled in the case of the reversible process. [8]

iii) With the aid of a process flow diagram involving the heating of water to generate pressurised steam followed by its expansion in a turbine to produce work, derive an expression for the enthalpy change for the steady state flow process, carefully defining the symbols used. [13]

2.

Starting with,

$$H = f(T, P)$$

i) Derive the Kirchoff's equation in the following form

$$L_2 = L_1 + \int_{T_2}^{T_1} \Delta C_p dT$$

where, L is the latent heat of evaporation with C_p representing the specific heat capacity at constant pressure. [15]

ii) Using the above expression, calculate the latent heat of evaporation for water at 100°C given that its liquid and vapour enthalpies at 90°C are 376.9 kJ kg^{-1} and 2659.7 kJ kg^{-1} respectively. [10]

The variation of C_p with temperature for the liquid and vapour phases are respectively given by the following expressions:

$$C_{pl}(\text{kJ/ kg K}) = 4.0 + 1.6 \times 10^{-5}\, T(K)$$
$$C_{pg}(\text{kJ/ kg K}) = 1.8 \times 10^{-3}\, T(K)$$

State any assumptions made in deriving your answer.

PLEASE TURN OVER

3.

Show that for an ideal gas,

i) $C_p = C_v + R$ [3]

For the same gas undergoing an adiabatic process show,

ii) $PV^{\gamma} = \text{constant}$ [5]

iii) $$W = \frac{P_1 V_1}{\gamma - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}\right]$$ [5]

where, W is the work involved per unit mass and γ is the ratio of specific heats.

iv) Calculate the exit pressure of a compressor adiabatically and reversibly compressing a mixture of saturated water and steam from 1 bara and specific volume of 1.5 $m^3\ kg^{-1}$ to 0.363 $m^3\ kg^{-1}$. [12]

4.

With reference to a clearly labelled *PV* diagram, calculate the work (W), heat (Q) as well as internal energy (ΔU) and enthalpy (ΔH) changes involved for each of the following steps for an ideal gas [5]

a) Adiabatic compression from 70°C and 1 bara to 150°C followed by [5]
b) Isobaric compression from 150°C to 70°C followed by [5]
c) Isothermal expansion from 70°C to 1 bara [5]

Calculate the corresponding values for W, Q, ΔU and ΔH for the overall process. [5]

PLEASE TURN OVER

5.

i) For a function $df = Mdx + Ndy$

When x and y are variables and

$$M = \left(\frac{dF}{dx}\right)_y \text{ and } N = \left(\frac{dF}{dy}\right)_x$$

it follows that

$$\left(\frac{dM}{dy}\right)_x = \left(\frac{dN}{dx}\right)_y$$

using the above, derive the following Maxwell equations

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

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

[12]

ii) Using the following mathematical expression

$$dZ = \left(\frac{\partial Z}{\partial X}\right)_Y dX + \left(\frac{\partial Z}{\partial Y}\right)_X dY$$

where $Z = f(X,Y)$

Show that

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

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

[13]

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6.

i) Draw a process flow diagram for a steam power plant. With reference to the diagram, draw a corresponding T/S diagram assuming the steam discharged from the turbine is superheated. [8]

Express the above cycle efficiency in terms of the enthalpy changes of the process stream. [3]

ii) A steam turbine with a power rating of 56,400 kW operates with steam at inlet conditions of 90 bara and 500°C, and discharges into a condenser at a pressure of 0.1 bara. Assuming a turbine isentropic efficiency of 0.75, determine the quality of the steam discharged from the turbine and the mass flow rate. [14]

7.

Express the Coefficient of Performance (COP) for a refrigeration cycle in terms of the process fluid enthalpy changes. [3]

i) Draw a simple process flow diagram for a conventional vapour compression refrigeration cycle. With reference to this diagram, draw the appropriate *T/S* diagram. [6]

ii) Express the COP for the above cycle in terms of enthalpy changes in the process. [2]

iii) A conventional vapour-compression refrigeration cycle uses ammonia as the refrigerant. Evaporation and condensation are at -3°C and 34°C respectively and the refrigeration rate is 2 kW. For a compressor efficiency of 0.75, determine the circulation rate of the refrigerant, the heat transfer rate in the condenser, the power requirement, the COP of the cycle and the COP of a Carnot refrigeration cycle operating between the same temperature levels. Assume that the throttle process is isenthalpic. [14]

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