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-06**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

06-C0217-3-110

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

1.

a) Describe what is meant by a state function. Explain if heat, work, internal energy and entropy are state functions. [5]

b) State the second law of thermodynamics and explain how a simple steam power cycle conforms to this law. [7]

c) Express the defining equation for entropy change, carefully explaining the symbols used. [3]

d) With the aid of a simple block diagram showing the irreversible heat exchange of a system with its surroundings, show that the net entropy for the process must increase. How does minimising the increase in entropy conform to the principles of sustainability? [10]

2.

Starting from the algebraic equation for the first law of thermodynamics for a closed system and using the defining equation for enthalpy

$$H = U + PV$$

(i) Derive the following Kirchoff's equation

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

where, L is the latent heat of vaporisation with ΔC_p representing the change in specific heat capacity at constant pressure. [15]

(ii) Using the above equation, calculate the latent heat of vaporisation for water at 250 °C given that its latent heat of vaporisation at 100 °C is 2257 kJ/kg and

$$\Delta C_p \text{ (kJ/kg K)} = 1\times10^{-3}\, T + 1\times10^{-5}\, T^2$$

[10]

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3.

Prove that for 1 mole of an ideal gas undergoing an adiabatic process

(i) $C_p = C_v + R$ [5]

and

(ii) $PV^{\gamma} = \text{constant}$ [10]

(iii) Also show that the work involved for the adiabatic reversible process is given by

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

where, γ is the ratio of the specific heats. [10]

4.

a) Given the equations for Helmholtz Free Energy, A, and Gibbs Free Energy, G, are respectively given by

$$A = U - TS \quad \text{and} \quad G = H - TS$$

and using the fact that for any mathematical variable, z, which is a function of x and y, we have:

$$z = f(x,y)$$

then

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy$$

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derive the following thermodynamics relations

(i) $S = -\left(\frac{\partial A}{\partial T}\right)_V = -\left(\frac{\partial G}{\partial T}\right)_P$ [5]

(ii) $V = \left(\frac{\partial H}{\partial P}\right)_S = \left(\frac{\partial G}{\partial P}\right)_T$ [5]

(iii) $P = -\left(\frac{\partial A}{\partial V}\right)_T = -\left(\frac{\partial U}{\partial V}\right)_S$ [5]

(iv) $T = \left(\frac{\partial H}{\partial S}\right)_P = \left(\frac{\partial U}{\partial S}\right)_V$ [5]

b) Explain the significance of the above equations. [5]

5.

Draw a Pressure/Volume behaviour diagram for a reciprocating compressor carefully indicating the intake volume, V_I, the swept volume, V_S and the clearance volume, V_c. Show that for the same compressor, the volumetric efficiency is given by

$$\eta_{vol} = \frac{V_I}{V_S} = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{1/\gamma} - 1\right]$$

where C is the clearance ratio, V_c/V_S. [14]

(i) Calculate the power requirement for a reciprocating compressor used to pressurise 5 kg/s of air from 1 bara and 30 °C to 50 bara. You may assume air behaves as an ideal gas with an average molar mass of 28 g/mol, R = 8.134 J/mol K and C_p = 29.1 J/gmol K.

The compression work is given by

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

[11]

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6.

a) Draw a basic process flow diagram for a vapour compression refrigeration cycle carefully denoting all the components used. With reference to the same figure, draw the corresponding T/S diagram for the refrigerant. [7]

b) A vapour compression refrigeration cycle using Refrigerant 12 as the working fluid operates between evaporator and condenser temperatures of 20°C and 40°C respectively. The mass flow rate of the refrigerant is 0.008 kg/s. Determine

(i) The compressor power in kW [4]
(ii) The refrigeration duty [4]
(iii) The coefficient of performance [4]
(iv) The coefficient of performance of a Carnot cycle operating between the same evaporator and condenser temperatures [4]

c) Identify and explain any unexpected features of your results in part (iv) above. [2]

You may assume saturated vapour enters and leaves the compressor, and saturated liquid leaves the condenser. Thermodynamics properties for the refrigerant are given in the accompanying tables.

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