# 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 : **17-MAY-05**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

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**TURN OVER**

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

**1.**

a) Describe the Second Law of Thermodynamics. Using a simple example involving the work done by a gas in moving a weight following the transfer of heat, demonstrate the applicability of the Second Law in practice. [10]

b) A gas is confined by a piston, 10 cm in diameter, on which rests a weight. The mass of the piston and weight together is 30 kg. The local acceleration of gravity is 9.805 m $s^{-2}$ and atmospheric pressure is 101.22 kPa.

i) What is the force (in Newtons) exerted on the gas by the atmosphere, the piston and the weight, assuming there is no friction. [5]

ii) What is the pressure of the gas, expressed in kPa? [5]

iii) If the gas cylinder is heated, it expands, pushing the weight upward. If the piston and the weight are raised to 40 cm, what is the work done by the gas, expressed in kJ? What are the changes in the potential energies of the piston and the weight? [5]

**2.**

State the First Law of thermodynamics for a closed process, carefully defining the symbols used. [5]

i) Liquid water at 100 °C and 1 bara has an internal energy of 9.0 kJ $kg^{-1}$ and a specific volume of 1.044 $cm^3$ $g^{-1}$.

a) What is its enthalpy? [5]

b) The water is brought to the vapour state at 200 $^0$C and 800 kPa, where its enthalpy and specific volume are 2,838.6 kJ $kg^{-1}$ and 260.79 $cm^3$ $g^{-1}$ respectively. Calculate $\Delta U$ and $\Delta H$ for the process. [5]

ii) In the following take $C_v$ = 20.8 J $mol^{-1}$ $°C^{-1}$ and $C_p$ = 29.1 J $mol^{-1}$ $°C^{-1}$ for nitrogen gas:

a) Five moles of nitrogen at 80 °C are contained in a rigid vessel. How much heat must be added to the system to raise its temperature to 300 °C if the vessel has a negligible heat capacity? If the mass of the vessel is 100 kg and its heat capacity is 0.5 J $g^{-1}$ $°C^{-1}$, what is the amount of heat required to raise the temperature of the gas to 300 °C? [5]

b) Three moles of nitrogen at 230 °C are contained in a piston/cylinder arrangement. How much heat must be extracted from this system, which is kept at constant pressure, to cool it to 80 °C if the heat capacities of the piston and cylinder are neglected? [5]

**PLEASE TURN OVER**

**3.**

i) With the aid of simple block diagrams, illustrate the basic principles of a heat engine, a refrigerator and a heat pump in terms of heat and work involved. For each system, express the corresponding efficiencies, carefully explaining the meanings of the symbols used. [15]

ii) State two corollaries of the Second Law of Thermodynamics. [5]

ii) What is the efficiency of a Carnot engine in terms of the two temperature levels. How can this efficiency be maximised in the case of a power plant using steam as the working fluid. Carefully explain the practical difficulties in achieving this. [5]

**4.**

Starting with the equation for the First Law of Thermodynamics for a closed system undergoing a reversible change and using the defining equations for Helmholtz Free Energy and Gibbs Free Energy, respectively given by

$$A = U - TS$$

$$G = H - TS$$

derive the following thermodynamics relationships:

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

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

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

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

[25]

**PLEASE TURN OVER**

**5.**

Starting with a simple process flow diagram for a steam power plant, draw the corresponding T/S diagram. [9]

The following data are for such a power plant:

| Location | Pressure (bara) | Temperature or quality (°C) |
|---|---|---|
| Leaving boiler | 20 | 300 (°C) |
| Entering condenser | 0.15 | 90% |
| Leaving condenser | 0.14 | 45 (°C) |
| Pump work = 4 kJ/kg | | |

Determine the following quantities per kilogram of steam flowing through the plant

a) Turbine work
b) Heat transfer in condenser
c) Heat transfer in boiler
d) Cycle efficiency

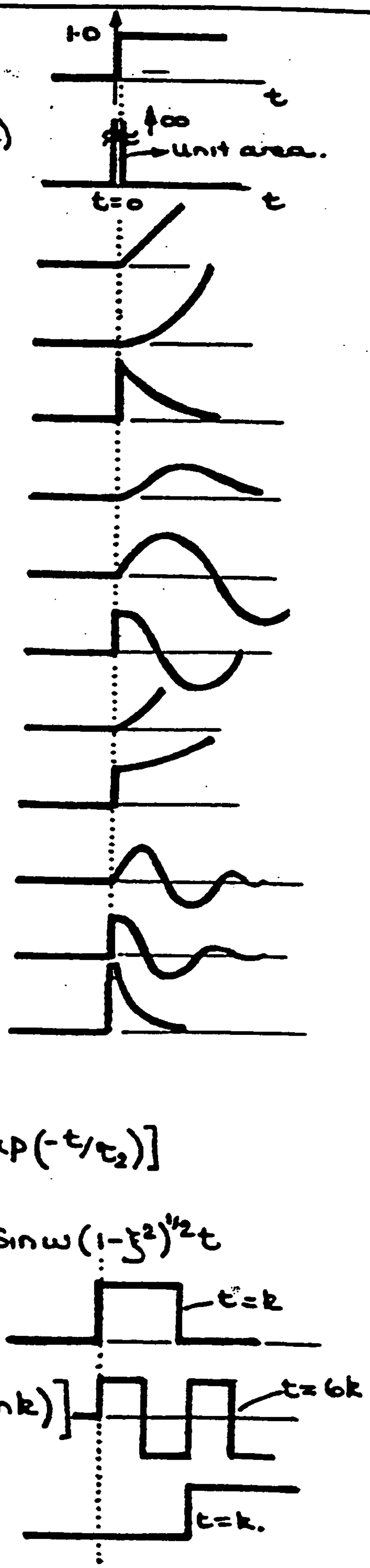
[16]

**6.**

Draw a process flow diagram for a 2-stage vapour compression refrigeration plant with a flash chamber. With reference to the same figure, draw the corresponding T/S diagram. [10]

Using the thermodynamics tables provided, calculate the coefficient of performance for the above refrigeration plant using ammonia as the refrigerant assuming that the flash chamber operates between - 30 °C and 26 °C, with the inter-cooler at - 10 °C. Also, vapour entering the second compressor is superheated by 50 K and the enthalpy of the superheated refrigerant leaving is 1713 kJ/kg. [15]

**END OF PAPER**




| FUNCTION AND REPRESENTATION. | LAPLACE TRANSFORM |
|---|---|
| Unit step function $u(t)$ | $1/s$ |
| Unit impulse function $\delta(t)$ (dirac $\delta$ function) | $1$ |
| $t \times u(t)$ | $1/s^2$ |
| $t^n \times u(t)$ | $n!/s^{n+1}$ |
| $e^{-at} \times u(t)$ | $\frac{1}{s+a}$ |
| $t^n e^{-at} \times u(t)$ | $\frac{n!}{(s+a)^{n+1}}$ |
| $\sin kt \times u(t)$ | $\frac{k}{s^2+k^2}$ |
| $\cos kt \times u(t)$ | $\frac{s}{s^2+k^2}$ |
| $\sinh kt \times u(t)$ | $\frac{k}{s^2-k^2}$ |
| $\cosh kt \times u(t)$ | $\frac{s}{s^2-k^2}$ |
| $e^{-at} \sin kt \times u(t)$ | $\frac{k}{(s+a)^2+k^2}$ |
| $e^{-at} \cos kt \times u(t)$ | $\frac{s+a}{(s+a)^2+k^2}$ |
| $\frac{1}{\sqrt{\pi t}} \times u(t)$ | $1/\sqrt{s}$ |
| $\frac{1}{\tau^n (n-1)!} t^{n-1} \exp[-t/\tau]$ | $\frac{1}{(\tau s+1)^n}$ |
| $\frac{1}{[\tau_1 - \tau_2]}\left[\exp(-t/\tau_1) - \exp(-t/\tau_2)\right]$ | $\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$ |
| $\frac{\omega}{(1-\xi^2)^{1/2}} \exp[-\xi \omega t] \sin \omega (1-\xi^2)^{1/2} t$ | $\frac{1}{\left[1 + \frac{2\xi s}{\omega} + \frac{s^2}{\omega^2}\right]}$ |
| $[u(t) - u(t-k)]$ | $1/s\,[1-e^{-ks}]$ |
| $\left[u(t) + 2\sum_{n=1}^{\infty}(-1)^n u(t-2nk)\right]$ | $1/s \tanh ks$ |
| $u(t-k)$ | $1/s\, e^{-ks}$ |
| $\frac{d^n f(t)}{dt^n}$ | $s^n f(s) - s^{n-1} f(0) - s^{n-2} f^1(0) \cdots - s f^{n-2}(0) - f^{n-1}(0)$ where $f^i(0) \equiv \left.\frac{d^i f(t)}{dt^i}\right\vert_{t=0}$ |

## THEOREMS

| | | | | |
|---|---|---|---|---|
| 1. | | $a\ f(t)$ | | $a\ F(s)$ |
| 2. | | $f_1(t) \pm f_2(t)$ | | $F_1(s) \pm F_2(s)$ |
| 3. | | $f(t/a)$ | | $a\ F(as)$ |
| 4. | | $e^{-at} f(t)$ | | $F(s + a)$ |
| 5. | Initial Value | $\lim_{t \to 0} f(t)$ | = | $\lim_{s \to \infty} sF(s)$ |
| 6. | Final Value | $\lim_{t \to \infty} f(t)$ | = | $\lim_{s \to 0} sF(s)$ |

NOTE: For more detailed list of transforms see "Applied Mathematics in Chemical Engineering", Mickley, Sherwood and Reed; also "Laplace Transform Tables and Theorems", McCollum and Brown.