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II/IV B.Tech. (Regular/Supplementary) DEGREE EXAMINATION

April, 2018

Fourth Semester

Time: Three Hours

Chemical Engineering

Engineering Thermodynamics

Maximum : 60 Marks

Answer Question No.1 compulsorily.

(1X12 = 12 Marks)

Answer ONE question from each unit.

(4X12=48 Marks)

1. Answer all questions

(1X12=12 Marks)

- Joule's Experiment: Mechanical stirring of known amount of liquid in an insulated vessel is conducted; It was proved that heat is a form of energy. Mechanical equivalence of heat is determined.
- Quasi Equilibrium: A process during which the system only deviates from equilibrium by an infinitesimal amount
- Thermodynamic Properties: All thermodynamic properties are intrinsic. Example: U, density,...
- Isothermal Compressibility: $\frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T$
- Mathematical Statement of Second Law: It is impossible by a cyclic process to convert all heat absorbed by system in to work done by system.
- Vander wall's Equation of State: $P = RT/(V-b) - a/V^2$
- Gibbs Free Energy Change: $G = H - TS$
- Throttling Process: Sudden expansion; Isenthalpic process
- Polytropic process: $PV^n = \text{Const}$; n is polytropic index/constant.
- T-S diagram for vapour compression cycle: Rectangle in V-L dome.
- Efficiency of an expander: Actual work obtained / Isentropic work obtained.
- Processes involved in vapour compression refrigeration cycle: Isothermal heat addition in evaporator, and rejection in condenser, adiabatic compression and expansion.

UNIT I

2. a) Write a short note on Thermodynamic Equilibrium

4M

Ans; Equilibrium is characterised by absence of tendency (driving force) towards change. Thermodynamic equilibrium means every other equilibrium like thermal, mechanical, chemical, electrical and other equilibria are satisfied. Thermodynamic equilibrium means complete equilibrium. Driving force for thermal process is temperature difference. Therefore it should be zero for thermal equilibrium. Similarly pressure difference is driving force for mechanical process. Concentration difference is driving force for chemical process. Chemical potential means molar gibb's free energy. It accounts for all these three driving forces. (3 eq's+1 definition = 4 M)

- The conditions of a gas change in a steady-flow process from 20°C and 1000 kPa to 60°C and 100 kPa. Devise a reversible nonflow process for accomplishing this change of state, and calculate change in internal energy and change in enthalpy for the process on the basis of 1 mol of gas. Assume for the gas that PV/T is constant, $C_v = (5/2) R$ and $C_p = (7/2) R$.

8M

Ans: Internal energy change = $nC_v\Delta T = 1 \times 2.5 \times 8.314 \times 40$ J/mol/K; Enthalpy energy change = $nC_p\Delta T = 1 \times 3.5 \times 8.314 \times 40$ J/mol/K (2+2+3=8 M)

(OR)

3. a) Derive Energy Balance Equation for a Control Volume System

8M

Ans: rate of energy in – rate of energy out = rate of energy accumulation

$$Q + W + m_{in} \left(U_1 + \frac{1}{2} u_1^2 + gZ_1 \right) - m_{out} \left(U_2 + \frac{1}{2} u_2^2 + gZ_2 \right) = \frac{d(Um_{cv})}{dt}$$

The work interaction can be in to forms 1. Shaft work W_s 2. PV work

$$Q + W_s + m_{in} \left(U_1 + P_1 V_1 + \frac{1}{2} u_1^2 + gZ_1 \right) - m_{out} \left(U_2 + P_2 V_2 + \frac{1}{2} u_2^2 + gZ_2 \right) = \frac{d(Um_{cv})}{dt}, \text{ where } U$$

is internal energy, P is pressure, V specific volume, u velocity, Z height above datum point and suffix 1 indicates inlet and suffix 2 the out let.

$$Q + W_s - \Delta \left(m \left(H + \frac{1}{2} u^2 + gZ \right) \right) = \frac{d(Um_{cv})}{dt}, \text{ for steady state } \frac{d(Um_{cv})}{dt} = 0.$$

Also if kinetic energy change and potential energy changes are negligible

$$Q + W_s = \Delta \left(m H \right); \text{ Also if process is adiabatic and there is no shaft work } \Delta \left(m H \right) = 0$$

(Fig = 2 M; 4 steps + explanation = 6 M)

- b) Air at 1 bar and 25°C enters a compressor at low velocity, discharges at 3 bar, and enters a nozzle in which it expands to a final velocity of 600 m/s at the initial conditions of pressure and temperature. If the work of compression is 240 kJ per kilogram of air, how much heat must be removed during compression? 4M

Ans: This is a cyclic process. Therefore apply I law to a flow process we get $\Delta H + \Delta \frac{U^2}{2} + g\Delta z = Q + W_s$; $(360000/2-0)=Q+240=?Q=240000-180000=60,000$ J/kg of air; Since expansion through nozzle is fast it is considered to be adiabatic. Therefore Q is nothing but Q of compressor. (2 balance equations and simplifications 2+2 = 4 M)

UNIT II

4. a) Derive expressions for calculating Q and H for an ideal gas for isothermal, isobaric and adiabatic processes (2+2+2 = 6 M) 6M

Ans: For $Q = \Delta U + \int P dv = Cp\Delta T = \Delta H$ for isobaric process.

For adiabatic process: $-\int P dv = \frac{R\Delta T}{\gamma-1}$; $\Delta U = C_v^{ig} \Delta T$; $Q=0$;

For isothermal process: $\Delta H=0$; $Q = \int P dv = RT \ln \frac{v_2}{v_1}$

- b) Draw and Explain PV diagram for pure substance 6M
 Ans: Vapor, liquid, solid phase, phase transition regions, triple point line, critical state point, isotherms should be shown clearly. (3+2+1 = 6M)

(OR)

5. a) Derive $Z = 1 + \frac{BP}{RT}$ 6M

Ans: From virial equation of state $PV = RT(1+B'P+C'P^2+\dots)$

Truncating to second term and replacing B' with B/R/T we have $Z = 1 + BP/R/T$ (3 steps x 2 = 6 M)

- b) State and Prove Carnot's Theorem (fig = 2 M; Theorem = 2 M; Explanation = 2 M) 6M

Ans: Engine E is assumed to be more efficient than Carnot engine. If $|Q_H|$ is heat input to Carnot engine and W_{net} is the work output then heat input ($|Q'_H|$) to engine E is less than $|Q_H|$ for the same work output. Let a Carnot heat engine running in opposite direction (refrigerator) be driven by the engine E as shown in fig. The net heat interaction to the hot reservoir is $|Q_H| - |Q'_H|$ which is > 0 (therefore is added to the hot reservoir). The net heat interaction to the cold reservoir is $(|Q_H| - W) - (|Q'_H| - W)$ which is < 0 (therefore taken out from the cold reservoir). The net work interaction of the set up is zero. Therefore the net result of the set up is that a net amount of heat is transferred from low temperature reservoir to high temperature reservoir spontaneously. This is violation of second law.

The violation has taken place because engine E is assumed to have efficiency greater than that of Carnot's engine operating between the same two temperatures. No violation of II law of TD is taking place when engine is assumed to have equal or less efficiency than that of Carnot's engine. Therefore no engine can have an efficiency greater than that of Carnot's engine.

UNIT III

6. a) Derive Maxwell's Equations by using Fundamental Property Relations (I law & II law = 2M; 4 Fundamental props = 4 M; Maxwell's relations = 2 M) 8M

For a closed reversible now flow process $dU = dQ - PdV$

From second law $dU = TdS - PdV$

$dH = dU + d(PV) = TdS - PdV + PdV + VdP = TdS + VdP$

$dG = dH - d(TS) = TdS + VdP - TdS - SdT = VdP - SdT$

$dA = dU - d(TS) = TdS - PdV - TdS - SdT = -PdV - SdT$

Though the above relations are derived for a reversible process only as the relations involve only state properties these equations do hold good for irreversible process also.

Therefore what ever is the number of phases present and whether the system is reactive or inert these equations are valid only if the system is closed.

What are Max Well's relations? And derive them.

From exact differential property relations if $F = F(T,P)$

$$dF = \left(\frac{\partial F}{\partial x}\right)_y dx + \left(\frac{\partial F}{\partial y}\right)_x dy \text{ and let } dF = Mdx + Ndy \text{ then it follows that } \left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

\therefore if $dU = TdS - PdV$ then it follows from exact differential property relation that

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V \text{ -----(1)}$$

similarly if follows from the fundamental property relation $dH = TdS + VdP$ that

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P \text{ -----(2)}$$

similarly if follows from the fundamental property relation $dG = VdP - SdT$ that

$$\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T \text{ -----(3)}$$

similarly if follows from the fundamental property relation $dA = -PdV - SdT$ that

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T \text{ -----(4)}$$

Equations 1-4 are called Max Well's relations. These relations are useful in converting other derivatives in to P,V and T derivatives.

- b) Write Expressions for dH and dS for liquids (2+2 = 4 M) 4M

$$dH = \left(\frac{\partial H}{\partial P}\right)_T dP + \left(\frac{\partial H}{\partial T}\right)_P dT$$

$$dH = [v - T\left(\frac{\partial S}{\partial P}\right)_T]dP + C_p dT$$

$$dH = [v - T\left(\frac{\partial v}{\partial T}\right)_P]dP + C_p dT$$

Similarly one can derive for $dS = [-T\left(\frac{\partial v}{\partial T}\right)_P]dP + C_p \frac{dT}{T}$

(OR)

7. a) Derive the equation for efficiency of compressors (First law 4 M; Rest = 2 M) 6M

$$\eta = \frac{W_{isentropic}}{W_{actual}}$$

- b) Saturated – Vapor steam at 100 kPa is compressed adiabatically to 300 kPa. If the compressor efficiency is 0.75, what is the work required?

For saturated steam at 100 kPa, Entropy is 7.3598 kJ/Kg K and Enthalpy is 2675.4 kJ/kg

For super-heated steam isentropic enthalpy at the discharge pressure is 2888.8 kJ/kg

Ans: Work required = (2888.8-2675.4)/0.75= 284.5333 kJ/kg (Efficiency = 2M; Isentropic work = 2 M; Data and simplification = 2 M) 6M

UNIT IV

8. a) Write a detailed note on Choice of a Refrigerant (any 4 points = 4 x 1 = 4 M) 4M

Ans :Choice of refrigerant depends on factors a) cost-it should be cheap b) availability – Readily available c) Toxicity – Non-toxic; d) Corrosivity – Non corrosive e) Environmentally friendly f) vapour pressure versus temperature should be such that refrigerant should not offer vacuum in evaporator and high pressure in condenser.

- b) Explain the Absorption Refrigeration Process with a neat diagram (fig 3 M;Explanation = 3 M; Min work 2 M) 8M

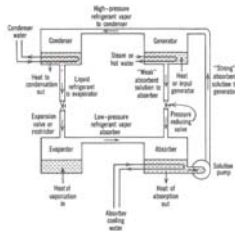


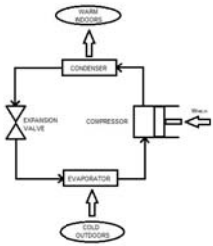
Fig. 20-2: Basic absorption refrigeration cycle.

The essential difference between a vapor-compression and an absorption refrigerator is in the different means employed for compression. The section of the absorption unit to the right of the dashed line in Fig. 9.4 is the same as in a vapor-compression refrigerator, but the section to the left accomplishes compression by what amounts to a heat engine. Refrigerant as vapor from the evaporator is absorbed in a relatively nonvolatile liquid solvent at the pressure of the evaporator and at relatively low temperature. The heat given off in the process is discarded to the surroundings at T_s . This is the lower temperature level of the heat engine. The liquid solution from the absorber, which contains a relatively high concentration of refrigerant, passes to a pump, which raises the pressure of the liquid to that of the condenser. Heat from the higher temperature source at T_H is transferred to the compressed liquid solution, raising its temperature

(OR)

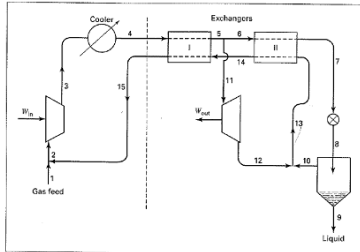
9. a) Write a note on Heat Pump (fig 2; Explanation = 2 M)

4M



The heat pump, a reversed heat engine, is a device for heating houses and commercial buildings during the winter and cooling them during the summer. In the winter it operates so as to absorb heat from the surroundings and reject heat into the building. Refrigerant evaporates in coils placed underground or in the outside air; vapor compression is followed by condensation, heat being transferred to air or water, which is used to heat the building. Compression must be to a pressure such that the condensation temperature of the refrigerant is higher than the required temperature level of the building.

- b) Explain the Claude Liquefaction Process with neat diagram (fig 3 M;Explanation 3 M;Balances 2 M)



A more efficient liquefaction process would replace the throttle valve by an expander, but operating such a device into the two-phase region is impractical. However, the Claude process, shown in Fig. 9.7, is based in part on this idea. Gas at an intermediate temperature is extracted from the heat-exchange system and passed through an expander from which it exhausts as a saturated or slightly superheated vapor. The remaining gas is further cooled and throttled through a valve to produce liquefaction as in the Linde process. The unliquefied portion, which is saturated vapor, mixes with the expander exhaust and returns for recycle through the heat-exchanger system.

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