CHE 31. Introduction to Chemical Engineering

Problem Set 4. Energy Balances

(Problems adopted from Elementary Principles of Chemical Process by Felder & Rousseau and Basic Principles and Calculations in Chemical Engineering by Himmelblau and Briggs)

Noted: Unless otherwise stated, the given pressure is absolute.

1. An ideal gas in a tank at 500°C and 100 kPa is compressed isothermally to 1000 kPa. What was the work (in J/g mol) of compression?

   Ans. W = 14800 J/gmol

2. A automobile weighing 2500 lb is traveling at 55 miles per hour when the brakes are suddenly applied bringing the vehicle to a stop. After the brakes have cooled to the ambient temperature, how much heat (in Btu) has been transferred from the brakes to the surroundings?

   Ans. Q = – 325 Btu

3. Calculate the change of enthalpy that occurs when 5 kg of water at 70°C in a closed vessel of 0.50 m^3 in volume are heated to 453.1 K and 1000 kPa. Also determine the final quality of the steam in the vessel.

   Ans. DH = 7520 kJ ; x = 0.51

4. Determine Q, W, ΔU and ΔH for the isothermal expansion of 1.31 mol of an ideal gas against a constant external pressure of 1.05 atm. This initial conditions are: T = 276 K and p_1 = 4.62 atm; the final pressure is p_2 = 2.21 atm for the gas.

   Ans. ΔH = ΔU = 0 ; W = – 745 J ; Q = 745 J

5. In a paper mill two steam chests are to be operated in parallel. Each has a volumetric capacity of 1000 cu.ft and each contains 18,000 lb of steam and liquid water. The first chests registers a pressure of 200 psia and in the other chest is 75 psia. What will be the pressure in the system after equilibrium has been attained. It may be assumed that no heat is exchanged with the surroundings, and no water exits to the surroundings.

   Ans. P = 130 psia

6. A Thomas flowmeter is a device in which heat is transferred at a measured rate from an electric coil to a flowing fluid, and the flow rate of the steam is calculated from the measured temperature increase of the fluid. Suppose a device of this sort is inserted in a stream of nitrogen, the current through the heating coil is adjusted until the amount of heat transferred is 1.25 kW, and the stream temperature goes from 30°C and 110 kPa before the heater to

34^oC and 110 kPa after the heater. If the specific enthalpy of nitrogen is given by the following formula

$$\hat{H}\ (kJ/kg) = 1.04\ [T(^oC) - 25]$$

what is the volumetic flow rate of the gas (L/s) before heating (i.e. at 30^oC and 110 kPa)?

Ans. 246 L/s

7. Saturated steam at a gauge pressure of 2.0 bar is to be used to heat a stream of ethane. The ethane enters a heat exchanger at 16^oC and 1.5 bar gauge at a rate of 795 m^3/min and is heated at constant pressure to 93^oC. The steam condenses and leaves the exchanger as a liquid at 27^oC. The specific enthalpy of ethane at the given pressure is 941 kJ/kg at 16^oC and 1073 kJ/kg at 93^oC. (a) How much energy (kW) must be transferred to the ethane to heat it from 16^oC to 93^oC? (b) Assuming that the energy transferred from the steam goes to heat the ethane, at what rate in m^3/s must steam be supplied to the exchanger?

   Ans. (a) Q = 5.47x10^3 kW (b) V= 1.27 m^3/s

8. A stream of hot water at 150 ^{0}F flowing at a rate of 50 gal/min is to be produced by mixing water at 60 ^{0}F and steam at 30 psia and 280 ^{0}F in a suitable mixer. What are the required flow rates of steam and cold water? Assume Q = 0.

   Ans. Cold Water = 377 lbm/min ; Steam = 32 lbm/min

9. The corrosion of aluminum in water is normally prevented by the tightly adhering oxide layer that forms on the aluminum. If this layer were absent, as when aluminum is amalgamated with mercury in an anaerobic atmosphere, the following reaction occurs:

$$2Al(s) + 6H_2O(l) \text{ =====> } 2A1(OH)_3(s) + 3H_2(g)$$

   What is the heat of formation of Al(OH)3?

   Ans. H_f^o = – 1276 kJ/mol $Al(OH)_3$

10. Superheated steam at 40 bar absolute and 500^0C flows at a rate of 250 kg/min to an adiabatic turbine, where it expands to 5 bar. The turbine develops 1500 kW. From the turbine the steam flows to a heater, where it is reheated isobarically (constant pressure) to its initial temperature. Determine the temperature of steam after passing thru the turbine and the heat required in the heater.

    Ans. T = 310^0C ; Q = 1663 kW

11. Steam produced in a boiler is frequently “wet” – that is, it is a mist composed of saturated water vapor and entrained liquid droplets. The quality of a wet steam is defined as the fraction on the mixture by mass that is vapor.

A wet steam at a pressure of 5.0 bar with a quality of 0.85 is isothermally "dried" by evaporating the entrained liquid. The flow rate of the dried steam is 52.5 m^3/h.

Determine the temperature at which the process occurs , the specific enthalpies of the wet and dry steams, and the total mass flow rate of the steam. Calculate also the heat input input (in kW) required for the evaporation process.

Ans. T = 151.8 0C ; H_{wet} = 640.1 kJ/kg ; H_{dry} = 2747.5 kJ/kg ; Q = 12 kW

12. Two hundred kg/min of steam enters a steam turbine at 350^{0}C and 40 bar through 7.5-cm diameter line and exits at 75^{0}C and 5 bar through a 5-cm line. If the exiting stream is a wet steam at 5.0 bar, what would its temperature be? How much work (in kW) is produced by the turbine?

    Ans. T = 151.8 0C ; W = 13,460 kW

13. Liquid water at 60 bar and 250^{0}C passes through an adiabatic expansion valve, emerging at a pressure P_2 and temperature T_2. If P_2 is low enough, some of the liquid evaporates.

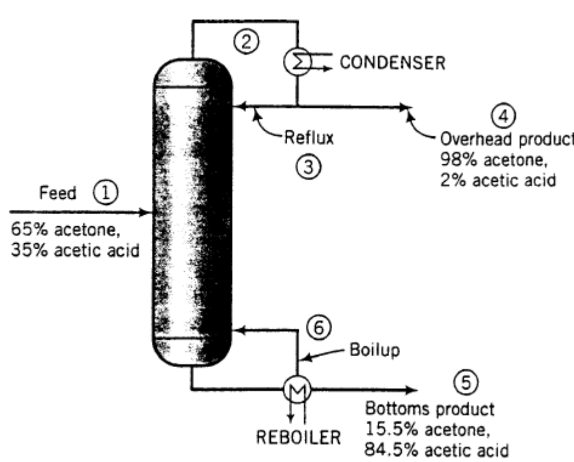
    If P_2 = 1.0 bar, determine T_2 and the fraction of the liquid water that evaporates. What is the value of P_2 if no evaporation would occur?

    Ans. T_2 = 99.6^{0}C ; fraction evaporated = 0.296 kg evaporated/kg liquid ; P_2 = 39.8 bar

14. A rigid 5.00-liter well-insulated vessel contains 4.00 L of liquid water in equilibrium with 1.00 L of water vapor at 250C. Heat is transferred to the water by means of an immersed electrical coil. The volume of the coil is negligible. Calculate the final temperature and pressure of the system and the mass of water vaporized if 2915 kJ is added to the water.

    Ans. T = 196.4^{0}C ; P = 14.4 bars ; Water Vaporized = 2.6 g

15. A mixture containing 65.0 mole% acetone (Ac) and the balance acetic acid (AA) is separated in a continuous distillation column at 1 atm. A flowchart for the operation is as follows:



The overhead stream from the column is a vapor that passes through a condenser. The condensed liquid is divided into two equal streams: one is take off as the overhead product (the distillate) and the other (the reflux) is returned to the column. The bottom stream from the column is a liquid that is partially vaporized in a reboiler. The liquid stream emerging from the reboiler is taken off as the bottoms product, and the vapor is returned to the column as boilup. It may be assumed that negligible heat is lost from the column, so that the only places in the system where external heat transfer takes place are at the condenser and reboiler.

Additional data for the process are as follows:

Stream Data

Feed ①	Liquid, 67.5°C, 65 mole% Ac, 35% AA
Overhead ②	Vapor, 63.0°C, 98 mole% Ac, 2% AA
Distillate ③, **Reflux** ④	Liquid, 56.8°C, 98 mole% Ac, 2% AA
Bottoms ⑤	Liquid, 98.7°C, 15.5 mole% Ac, 84.5% AA
Boilup ⑥	Vapor, 98.7°C, 54.4 mole% Ac, 45.6% AA

Thermodynamic Data

	$\hat{H}$(cal/mol)			
	Acetone		*Acetic Acid*	
T(°C)	$\hat{H}_l$	$\hat{H}_v$	$\hat{H}_l$	$\hat{H}_v$
56.8	0	7205	0	5723
63.0	205	7322	194	6807
67.5	354	7403	335	6884
98.7	1385	7946	1312	7420

Taking 100 mol of feed as basis, calculate the (a) net heat requirement (in cal) for the process; (b) required heat input to the boiler; and (c) required heat removal from the condenser.

Ans. (a) $1.82\text{x}10^4$ cal (b) $+8.95\text{x}10^5$ cal (c) $-8.77\text{x}10^5$ cal