Department of Chemical Engineering
Thapar Institute of Engineering & Technology, Patiala
Course: Material and Energy Balances
UCH301

Course Instructor:
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- Enthalpy change is evaluated using tabulated enthalpy data or using heat capacities
- $\Delta H = \int C_p(T)\, dT$ (C_p as a function of T)

  $Cp(T) = a + bT + CT^2 + dT^3$ (a, b, c, d are constants)
- Heat capacity of a mixture can be evaluated as

  $C_{p,mix} = \sum y_i C_{p,i}$

  If Cp_i and Cp_{mix} are expressed in molar units, then y_i should be mol fraction of the i^{th} component, if Cp_i and Cp_{mix} are expressed in mass units, then y_i should be mass fraction

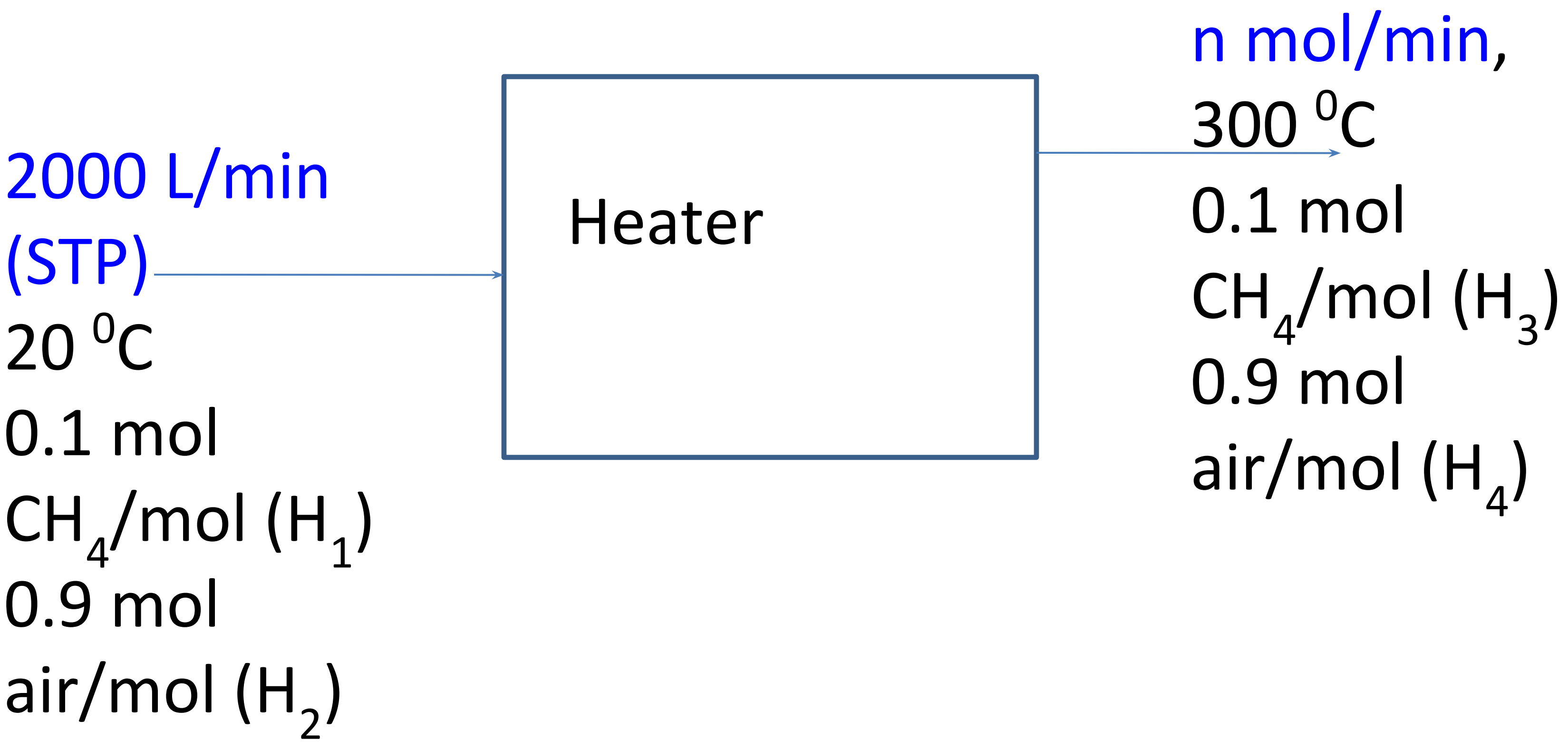
- Latent heat – The specific enthalpy change associated with the transition of a substance from one phase to another at constant temperature and pressure is known as latent heat of the phase change

Problem

- A stream containing 10% CH_4 and 90% air by volume is to be heated from 20 ^{0}C to 300 ^{0}C. Calculate the required rate of heat input in kW if the gas flow rate is 2000 l/min at STP.
- Reference for methane (at 20 deg C and 1 atm) so that $H_{sp,methane}$ at inlet =0
- Reference for air (at 25 ^{o}C and 1 atm)

  $H_{sp,\ air}$ at inlet = -0.15 kJ/mol;

$H_{sp,\ air}$ at outlet = 8.17 kJ/mol (at 300 deg C and 1 atm)


2000 L/min (STP)
20 ^{0}C
0.1 mol CH_4/mol (H_1)
0.9 mol air/mol (H_2)
Heater
n mol/min,
300 ^{0}C
0.1 mol CH_4/mol (H_3)
0.9 mol air/mol (H_4)

SOLUTION

From E.B. $Q = \Delta H$ (assuming kinetic and potential changes to be zero)

$\Delta H = \sum n_i H_{i\ (outlet)} - \sum n_i H_{i\ (inlet)}$

CH_4: $a = 0.03431$; $b = 5.469\times10^{-5}$; $c = 0.3661\times10^{-8}$

$d = -11.0\times10^{-12}$

$H_2 = -0.15$ kJ/mol

$H_3 = \int Cp(T)dT$ (from 20 to 300 °C)

$= 12$ kJ/mol

$H_4 = 8.17$ kJ/mol

Total moles entering (from ideal gas law)=

2000/22.4 = 89.3 mol/min

$$\Delta H = \sum n_i H_{i\ (outlet)} - \sum n_i H_{i\ (inlet)}$$

$$= 0.1*89.3*12+0.9*89.3*8.17$$

$$-0.1*89.3*0-0.9*89.3*(-0.15)$$

$$= 776 \text{ kJ/min} = 776/60 = 12.9 \text{ kW}$$

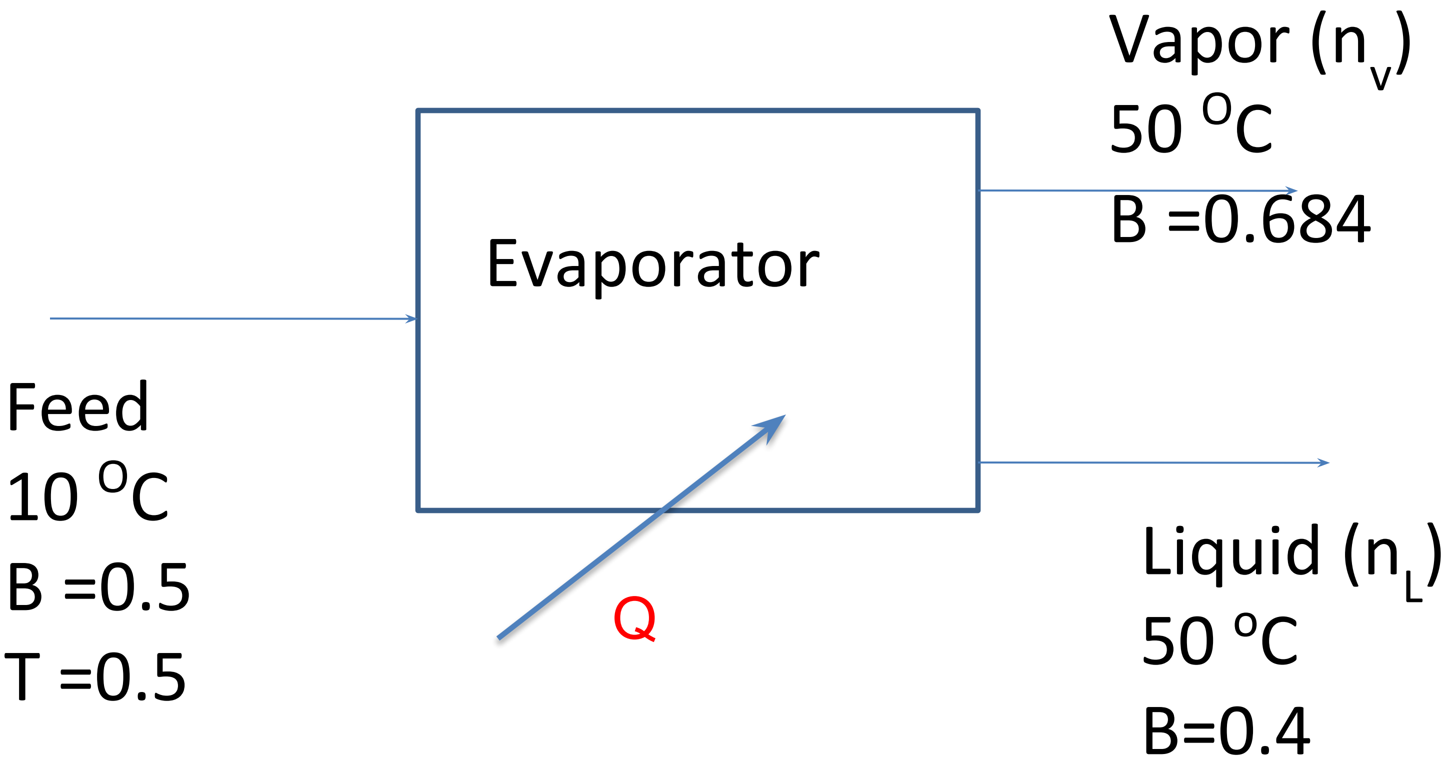
Heat to be supplied = 12.9 kJ/s

Problem (Partial vaporization of a mixture)

- An equimolar liquid mixture of benzene (B) and toulene (T) at 10 ^{0}C is fed continuously to a vessel in which the mixture is heated to 50 ^{0}C. The liquid product is 40 mole% B, and the vapor product is 68.4 mol% B. How much heat must be transferred to the mixture per 100 mol of feed.

(Boiling point of B= 80.1 ^{0}C, and T = 110.62 ^{0}C)

Sketch



Vapor (n_v)
50 ^oC
B =0.684
Evaporator
Feed
10 ^oC
B =0.5
T =0.5
Q
Liquid (n_L)
50 ^oC
B=0.4

Data

References: B(l, 10 ^{0}C, 1 atm), T(l, 10 ^{0}C, 1atm)

	n_{in}	H_{in}
B (L)	50	0
T (L)	50	0
B (v)	---	----
T (v)	----	----

Solution

- Basis : 100 mol of feed

Since there are two components, two material balance equations would give the values of n_v and n_L

Total mol balance: $100 = n_v + n_L$

Benzene balance: $50 = 0.684\, n_v + 0.4\, n_L$

$n_v = 35.2$ mol; $n_L = 64.8$ mol

B in liquid product = 64.8* 0.4 = 25.9 mol

T in liquid product = 64.8*0.6 = 38.9 mol T

Similarly, n_v contains 24.1 mol B, and 11.1 mol T

Energy balance for this process reduces to:

$Q = \Delta H = \sum n_i H_{i\,(outlet)} - \sum n_i H_{i\,(inlet)}$

Now, Liquid enthalpy evaluation is straightforward

- $H_{BL} = \int Cp(T)dT \quad (10 – 50\ ^0C)$
- $H_{TL} = \int Cp(T)dT \quad (10 – 50\ ^0C)$

Vapor stream enthalpy evaluation requires the latent heat be used along with sensible heat changes

$H_{Bv} = \int Cp_{BL}(T)dT + \Delta Hv_{B\,(80.1\ ^0C)} + \int Cp_{Bv}(T)dT$

$(10 \text{ to } 80.1\ ^0C) \qquad (80.1 \text{ to } 50\ ^0C)$

Similarly for toluene vapor:

$$H_{Tv} = \underset{(10 \text{ to } 110.62\ ^0C)}{\int Cp_{TL}(T)dT} + \Delta Hv_{T\,(110.62\ ^0C)} + \underset{(110.62 \text{ to } 50\ ^0C)}{\int Cp_{Tv}(T)dT}$$

- Data for latent heat of vaporization
- Hv_B = 30.765 kJ/mol
- Hv_T = 33.47 kJ/mol

Constants for Benzene and Toluene for C_p:

Benzene (L): $a\times10^3 = 126.5$; $b \times10^5 = 23.4$

Benzene (v): $a\times10^3 = 74.06$; $b \times 10^5 = 32.95$

Toluene (L): $a\times10^3 = 148.8$; $b \times 10^5 = 32.4$

Toluene (v): $a\times10^3 = 94.18$; $b \times 10^5 = 38$

- Substituting Cp in as a function of T in the enthalpy expressions, and integrating, the enthalpies can be evaluated:

$H_{BL} = \int Cp(T)dT \quad (10 - 50\ ^0C) = 5.332$ kJ/mol

$H_{TL} = \int Cp(T)dT\ (10 - 50\ ^0C) = 6.34$ kJ/mol

$H_{Bv} = 37.52$ kJ/mol

$H_{Tv} = 42.93$ kJ/mol

Once the specific enthalpies are evaluated, the information from material balance about the moles of each species in each stream is used:

$$Q = \Delta H = \sum n_i H_{i\ (outlet)} - \sum n_i H_{i\ (inlet)}$$

$\Delta H = 25.9*5.332+38.9*6.34+24.1*37.52+11.1*42.93$

$- 100*0 = 1770$ kJ

Heat to be supplied =Q= 1770 kJ