Department of Chemical Engineering
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Course: Material and Energy Balances UCH301

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ENERGY BALANCES

Why Energy Balance is Required

- The cost of energy consumed in a Chemical Industry/plant necessitates economical use of the energy.

- As an engineer, your job would be to account for the energy that flows into and out of a process and to determine the energy requirement of the process.

Internal Energy

- Internal energy (U) is a macroscopic measure of molecular energies. Because no instrument exist for the measurement of U directly, it has to be calculated from certain other variables that can be measured at macroscopic level.
- Change in internal energy can be calculated by using the following equation (from Ref state):

$$\hat{U}_2 - \hat{U}_1 = \int_{T_1}^{T_2} C_v \, dT$$

Enthalpy

- Enthalpy is a combination of two terms that appear in the energy balance equation for open systems.

$$H = U + pV$$

Here, P is pressure, and V is volume.

- Enthalpy change can be calculated using the following expression (from reference state):

$$\hat{H}_2 - \hat{H}_1 = \int_{T_1}^{T_2} C_p \, dT$$

Reference State

- We can never know the absolute values of *U* and *H* for a species at a given state.
- However, we never need to know the absolute values of *U* or *H* at specified states: we only need to know □*U* and □*H* for specified *changes* of state (and we can determine these quantities experimentally).
- We may, therefore, arbitrarily choose a **reference state** for a species and determine □ΔU □$= U - U_{ref}$, or $\Delta H = U - U_{ref}$ for the transition from the reference state to other state.

Energy Balance

- Energy balance is the account of the energy entering and leaving the process and the energy requirement of the process
- General Energy Balance equation:

$$\begin{pmatrix}\text{Accumulation}\\ \text{within system}\end{pmatrix} = \begin{pmatrix}\text{Flow In}\\ \text{through system boundaries}\end{pmatrix} - \begin{pmatrix}\text{Flow Out}\\ \text{through system boundaries}\end{pmatrix}$$
$$+ \begin{pmatrix}\text{Generation}\\ \text{within system}\end{pmatrix} - \begin{pmatrix}\text{Consumption}\\ \text{within system}\end{pmatrix}$$

Energy Balance for closed systems (without chemical reaction)

- $\Delta E = \Delta U + \Delta P + \Delta K = Q + W$

  $\Delta U = U_2 - U_1$

  $\Delta P = P_2 - P_1$

  $\Delta K = K_2 - K_1$

  Heat input to process +ve

  Work done on the process +ve

Energy Balance for Open Systems (without chemical reaction)

Energy entering with mass flow = $(u_1+k_1+p_1)m_1$

Energy leaving with mass flow = $(u_2+k_2+p_2)m_2$

Net Energy Transfer as heat to the system =Q

Net work done (mech/elec) on the system = W

Net energy transfer as work to introduce and remove masses = $p_1v_1m_1$ and $p_2v_2m_2$

substituting these quantities in e.b. equation

- $\Delta E = (u_1+k_1+p_1)m_1 - (u_2+k_2+p_2)m_2+Q+W$
  $+(pv)_1m_1-(pv)_2m_2$

Combining $(pv)_1m_1$ with u_1m_1 and $(pv)_2m_2$ with u_2m_2, taking $\Delta U + \Delta(pV) = \Delta H$

$\Delta E = Q+W- (\Delta H+\Delta K+\Delta P)$ (at steady state $\Delta E=0$)

$Q+W = (\Delta H+\Delta K+\Delta P)$ for steady flow process

For multiple input and output streams:

$(\Delta H+\Delta K+\Delta P)= \sum m_i(h_i+k_i+p_i)_{out}-\sum m_i(h_i+k_i+p_i)_{in}$

Procedure for Applying Energy Balance

- Perform all required material balance calculations.
- Write the appropriate form of the energy balance (closed or open system) and delete any of the terms that are either zero or negligible for the given process system.
- Choose a reference state—phase, temperature, and pressure—for each species involved in the process.

- Prepare a table with columns for initial and final amounts of each species (m_i or n_i) and internal energies (U_i) or enthalpies (H_i) relative to the chosen reference states.
- Calculate all required values of U_i or H_i and insert the values in the appropriate places in the table.
- Calculate Internal Energy Change or Enthalpy change as the case may be.

- Calculate any work, kinetic energy, or potential energy terms that you have not dropped from the energy balance.
- Solve the energy balance for the unknown variable value.

Closed System: $\Delta U+\Delta P+\Delta K = Q+W$

Open System: $0 = \sum m_i(h_i+k_i+p_i)_{in} - \sum m_i(h_i+k_i+p_i)_{out} + Q + W$

or $H_{out}-H_{in} = \Delta H = Q+W$