0905322- Chemical Engineering Thermodynamics I
Lecture 3: First Law of Thermodynamics

Ali Khalaf Al-Matar (aalmatar@ju.edu.jo)
Chemical Engineering Department

The University of Jordan
Amman, Jordan
2019

Outline

- Energy Change of a System, ΔE_{system}
- Total Energy E of a System
- Energy Balance
- Forms of Energy Balance (EB)
- Formal Sign Convention
- First Law of Thermodynamics

Energy Change of a System, ΔE_{system}

- The determination of the energy change of a system during a process involves the evaluation of the energy of the system at the beginning and at the end of the process, and taking their difference.

$$\text{Energy Change} = \text{Eenergy at final state} - \text{Energy at initial state}$$

$$\Delta E_{\text{system}} = E_{\text{final}} - E_{\text{initial}} = E_2 - E_1$$

THE UNIVERSITY OF JORDAN

Total Energy E of a System

- In the absence of **nuclear changes**, **electric**, **magnetic**, and **surface tension effects** (i.e., for **simple compressible systems**), the change in the total energy of a system during a process is the sum of the changes in its internal, kinetic, and potential energies.

$$\Delta E = \Delta U + \Delta \mathrm{KE} + \Delta \mathrm{PE}$$

$$\Delta \mathrm{U} = m\left(u_2 - u_1\right) \qquad \Delta \mathrm{KE} = \frac{1}{2} m\left(V_2^{\,2} - V_1^{\,2}\right) \qquad \Delta \mathrm{PE} = mg\left(z_2 - z_1\right)$$

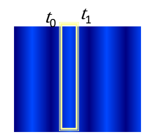
THE UNIVERSITY OF JORDAN

Forms of Energy Balance (EB)

Balance

Integral (Difference)

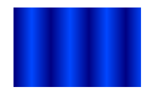
$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}} \quad \text{(kJ)}$$



Difference (finite time)

Differential

$$\dot{E}_{\text{in}} - \dot{E}_{out} = \frac{dE_{\text{system}}}{dt} \quad \text{(kW)}$$



$\lim_{t \to 0}$

Material balance (**MB**) is a key in solving many problems in combination with energy balance.

$$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \quad \text{(kg)} \qquad \dot{m}_{\text{in}} - \dot{m}_{out} = \frac{dm_{\text{system}}}{dt} \quad \text{(kg/s)}$$

THE UNIVERSITY OF JORDAN

Difference Form of the Balance Equations

$$\begin{aligned}
\begin{pmatrix}\text{amount of } \theta \text{ in the} \\ \text{system at time t+}\Delta\text{t}\end{pmatrix} - \begin{pmatrix}\text{amount of } \theta \text{ in the} \\ \text{system at time t}\end{pmatrix} &= \begin{pmatrix}\text{amount of } \theta \text{ that entered the system across} \\ \text{system boundaries between t and t+}\Delta\text{t}\end{pmatrix} \\
&- \begin{pmatrix}\text{amount of } \theta \text{ that left the system across} \\ \text{system boundaries between t and t+}\Delta\text{t}\end{pmatrix} \\
&+ \begin{pmatrix}\text{amount of } \theta \text{ generated within the} \\ \text{system between t and t+}\Delta\text{t}\end{pmatrix}
\end{aligned}$$

THE UNIVERSITY OF JORDAN

Differential Form of the Balance Equation

$$\frac{\theta(t+\Delta t)-\theta(t)}{\Delta t}=(\text{rate at which } \theta \text{ enters the system across system boundaries})$$
$$-(\text{rate at which } \theta \text{ leaves the system across system boundaries})$$
$$+(\text{rate at which } \theta \text{ is generated within the system})$$

$$\text{Take the limit as } \Delta t \to 0 \Rightarrow \frac{d\theta}{dt}=\lim_{\Delta t \to 0}\frac{\theta(t+\Delta t)-\theta(t)}{\Delta t}$$

$$\frac{d\theta}{dt}=(\text{rate of change of } \theta \text{ in the system})$$
$$=(\text{rate at which } \theta \text{ enters the system across system boundaries})$$
$$-(\text{rate at which } \theta \text{ leaves the system across system boundaries})$$
$$+(\text{rate at which } \theta \text{ is generated within the system})$$

THE UNIVERSITY OF JORDAN

This equation is general and applies to both conserved and nonconserved quantities.

Conservation of Mass

- Substitute θ with m to obtain the proper form
  - **Differential mass balance**

$$\frac{dm}{dt}=\sum_{k=1}^{K}\dot{m}_k$$

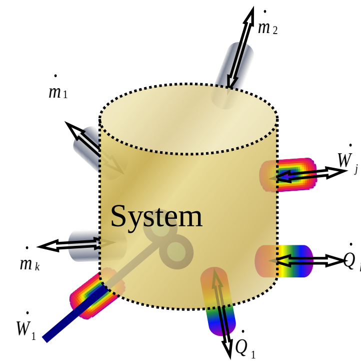
  - **Integral mass balance**

$$m(t_2)-m(t_1)=\int_{t_1}^{t_2}\left(\sum_{k=1}^{K}\dot{m}_k\right)dt$$

THE UNIVERSITY OF JORDAN

First Law of Thermodynamics (Energy Balance)

- The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process.
  - The boundaries of the system may be **stationary** or **moving**. If they are moving, it can be due to expansion/contraction, or the system as a whole is moving, or both.
  - Mass may flow into **one, several, all, or none** of the k entry ports.
  - Energy
    - In the form of **heat** may enter or leave the system across its boundaries.
    - In the form of **work** may enter or leave the system across its boundaries.



$$\dot{m} = \sum_{k=1}^{K} \dot{m}_k \qquad \dot{W} = \sum_{j=1}^{J} \dot{W}_j, \qquad \dot{Q} = \sum_{l=1}^{L} \dot{Q}_l.$$

Formal Sign Convention

- Quantity
  - Heat Q
    - To a system: +ve
    - From a system: -ve
  - Work W
    - Done by a system: +ve
    - Done on a system: -ve
  - Mass
    - Into a system: +ve
    - Out of a system: -ve

Conservation of Energy

- Substitute θ with the sum of the internal, kinetic, and potential energy of the system

$$\theta = E = m\left(u + \frac{V^2}{2} + gz\right) = U + m\left(\frac{V^2}{2} + gz\right)$$

- Energy is a conserved quantity. Consequently, the energy balance takes the form

$$\frac{d}{dt}\left[U + m\left(\frac{V^2}{2} + gz\right)\right] = \text{rate at which energy enters a system}$$

$$- \text{ rate at which energy leaves a system}$$

THE UNIVERSITY OF JORDAN

Integral and Differential Forms of the First Law of Thermodynamics

$$\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}} = \left(Q_{\text{in}} - Q_{\text{out}}\right) + \left(W_{\text{in}} - W_{\text{out}}\right) + \left(E_{\text{mass,in}} - E_{\text{mass,out}}\right)$$

$$\Delta\left[m\left(u + \frac{V^2}{2} + gz\right)\right]_{\text{system}} = Q - W + \int \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right) dt$$

$$\frac{dE_{\text{system}}}{dt} = \dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \left(\dot{Q}_{\text{in}} - \dot{Q}_{\text{out}}\right) + \left(\dot{W}_{\text{in}} - \dot{W}_{\text{out}}\right) + \left(\dot{E}_{\text{mass,in}} - \dot{E}_{\text{mass,out}}\right)$$

$$\frac{d}{dt}\left[m\left(u + \frac{V^2}{2} + gz\right)\right]_{\text{system}} = \dot{Q} - \dot{W} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right)$$

THE UNIVERSITY OF JORDAN

Special Cases of the First Law of Thermodynamics

$$\frac{d}{dt}\left[m\left(u+\frac{V^2}{2}+gz\right)\right]_{\text{system}} = Q - W + \sum_i \dot{m}_i\left(h_i+\frac{V_i^2}{2}+gz_i\right)$$

Cancels out for steady state systems

$$\frac{d}{dt}\left[m\left(u+\frac{V^2}{2}+gz\right)\right]_{\text{system}} = Q - W + \sum_i \dot{m}_i\left(h_i+\frac{V_i^2}{2}+gz_i\right)$$

Cancels out for closed systems

Cancels out for adiabatic systems

Cancels out for systems with no work on ot out of the system

THE UNIVERSITY OF JORDAN

Usually, but not always, KE and PE are negligible compared to either u or h.