

Introduction to Material and Energy Balances

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Fundamental concepts for chemical, process, environmental, and mechanical engineering

1. Why Material & Energy Balances Matter

Reason	What It Shows
Design	Size of reactors, separators, heat exchangers, and utility systems
Safety	Limits of accumulation, pressure, temperature, and hazardous releases
Economics	Raw material costs, product yields, energy consumption, waste treatment
Environmental compliance	Emission limits, carbon footprint, life cycle analysis

2. Basic Terminology

Symbol	Meaning	Typical Units
$\dot{n}$	Molar flow rate	$\text{kmol}\cdot\text{h}^{-1}$
$\dot{m}$	Mass flow rate	$\text{kg}\cdot\text{h}^{-1}$
$\dot{V}$	Volumetric flow rate	$\text{m}^3\cdot\text{h}^{-1}$
F_i	General flow of component i (mass, mol, or vol)	
$\dot{Q}$	Heat transfer rate	kW
$\dot{W}$	Shaft work rate	kW
ΔH	Enthalpy change	$\text{kJ}\cdot\text{kmol}^{-1}$
ΔU	Internal energy change	$\text{kJ}\cdot\text{kmol}^{-1}$
$\dot{E}$	Total energy flow (heat + work + enthalpy)	kW

3. The General Balance Equation

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For any **conserved property** (Φ) (mass, species, energy, momentum) applied to a control volume (CV):

$$\boxed{\displaystyle \underbrace{\sum \dot{\Phi}_{\text{in}}}_{\text{inflow}} \; ; - \; \underbrace{\sum \dot{\Phi}_{\text{out}}}_{\text{outflow}} \; ; + \; \underbrace{\dot{\Phi}_{\text{gen}}}_{\text{generation}} \; ; = \; \underbrace{\frac{d}{dt} \left(\Phi_{\text{CV}} \right)}_{\text{accumulation}} }$$

- **Steady-state** ? accumulation term = 0.
 - **Batch (closed) system** ? no flow terms; only generation and accumulation.
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4. Material (Mass) Balances

4.1 Overall Mass Balance

$$\left[\sum \dot{m}_{\text{in}} - \sum \dot{m}_{\text{out}} = \frac{dM_{\text{CV}}}{dt} \right]$$

- **Closed batch:** ($\dot{m}_{\text{in}} = \dot{m}_{\text{out}} = 0 \Rightarrow \frac{dM}{dt} = 0$)
(mass constant).
- **Open steady-state:** ($\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}}$).

4.2 Component (Species) Balance

For component i :

$$\left[\underbrace{\sum \dot{n}_{i,\text{in}}}_{\text{in}} - \underbrace{\sum \dot{n}_{i,\text{out}}}_{\text{out}} + \underbrace{\dot{r}_i V}_{\text{generation/consumption}} = \underbrace{\frac{d n_i}_{dt}}_{\text{accumulation}} \right]$$