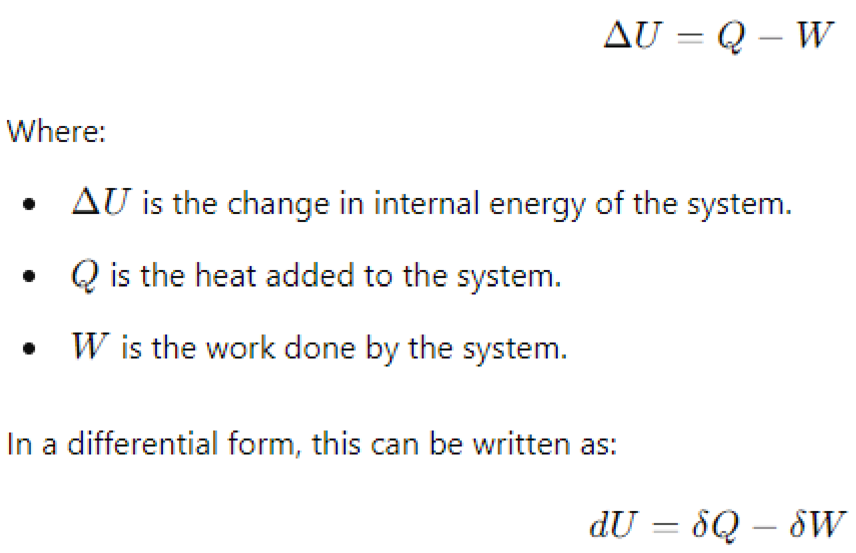
Energy Balance for Closed Systems

Introduction

In thermodynamics, energy balance is a fundamental concept used to analyze the energy exchange within a system. A closed system, also known as a control mass, is one where no mass enters or leaves the system boundaries. However, energy in the form of heat, work, and internal energy can cross the boundary of a closed system. The first law of thermodynamics, which is the principle of conservation of energy, is applied to analyze these energy exchanges.

First Law of Thermodynamics for Closed Systems

The first law of thermodynamics for a closed system states that the change in the internal energy of the system is equal to the difference between the heat added to the system and the work done by the system. Mathematically, this can be expressed as:



$$\Delta U = Q - W$$

Where:

- ΔU is the change in internal energy of the system.
- Q is the heat added to the system.
- W is the work done by the system.

In a differential form, this can be written as:

$$dU = \delta Q - \delta W$$

Types of Energy in a Closed System

The total energy in a closed system can be categorized into internal energy (U), kinetic energy (KE), and potential energy (PE). The internal energy consists of the microscopic energy of the molecules, while kinetic and potential energies are associated with the macroscopic movement and position of the system, respectively.

$$E_{\text{total}} = U + KE + PE$$

For many practical problems, kinetic and potential energy changes are negligible, so the energy balance equation simplifies to focus primarily on internal energy.

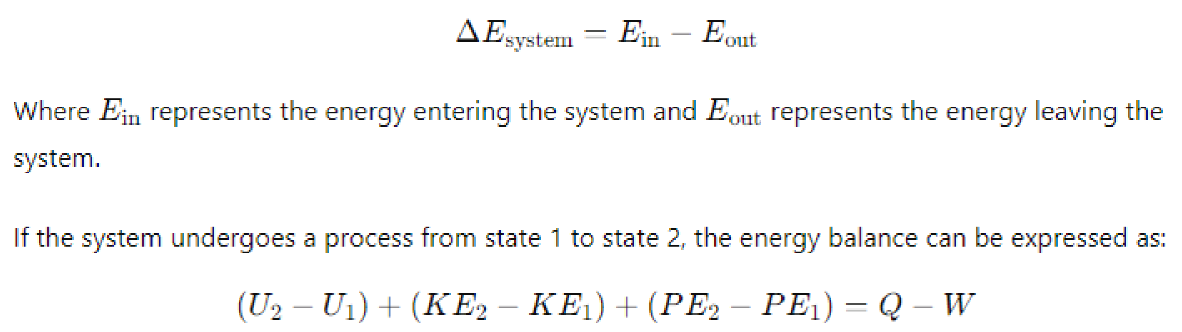
Heat and Work Interactions

1. Heat (Q): Heat is energy transfer due to temperature difference. Heat added to the system increases its internal energy, while heat lost decreases it.

2. Work (W): Work is the energy transfer due to force applied over a distance or other means such as electrical work. Work done by the system reduces its internal energy, while work done on the system increases it.

Energy Balance Equation for Closed Systems

For a closed system, the general energy balance equation accounting for heat and work interactions can be written as:



$$\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}}$$

Where E_{in} represents the energy entering the system and E_{out} represents the energy leaving the system.

If the system undergoes a process from state 1 to state 2, the energy balance can be expressed as:

$$(U_2 - U_1) + (KE_2 - KE_1) + (PE_2 - PE_1) = Q - W$$

Applications of Energy Balance in Closed Systems**

Energy balance in closed systems is crucial in understanding processes such as:

- Heating or cooling of gases and liquids in a container.
- Compression or expansion of gases in a piston-cylinder assembly.
- Phase change processes where heat is added or removed without mass exchange.

Energy Balance for Steady Flow Systems

Introduction

Steady flow systems, also known as control volumes, differ from closed systems in that they allow the continuous flow of mass across the system boundaries. These systems are typically used to model devices such as turbines, compressors, pumps, and heat exchangers, where mass flow is constant over time. The first law of thermodynamics is adapted for such systems to analyze energy transfer in and out of the control volume.

First Law of Thermodynamics for Steady Flow Systems

The first law of thermodynamics for a steady flow system states that the rate of energy entering the control volume must equal the rate of energy leaving, considering the work done and the heat transferred. For a control volume, the energy balance can be expressed as:

$$\dot{Q} - \dot{W} = \dot{m}\left(h_2 + \frac{v_2^2}{2} + gz_2\right) - \dot{m}\left(h_1 + \frac{v_1^2}{2} + gz_1\right)$$

Where:

- $\dot{Q}$ is the rate of heat transfer to the system.
- $\dot{W}$ is the rate of work done by the system.
- $\dot{m}$ is the mass flow rate through the system.
- h is the specific enthalpy ($h = u + Pv$).
- $\frac{v^2}{2}$ is the kinetic energy per unit mass.
- gz is the potential energy per unit mass.

Steady Flow Energy Equation

For many practical cases, the steady flow energy equation can be simplified depending on the type of system being analyzed. For instance, in a nozzle, changes in potential energy and heat transfer are often negligible, leading to:

$$\frac{v_2^2}{2} - \frac{v_1^2}{2} = h_1 - h_2$$

Similarly, for turbines, where heat transfer is often negligible, the equation simplifies to:

$$\dot{W}_{\text{turbine}} = \dot{m}(h_1 - h_2)$$

Specific Enthalpy and Energy Balance

Enthalpy H is a key property in the analysis of steady flow systems. It is defined as:

Enthalpy incorporates the effects of both internal energy and flow work, making it particularly useful in steady flow processes.

Applications of Energy Balance in Steady Flow Systems

The concept of energy balance is vital in designing and analyzing various engineering systems, such as:

-Turbines and Compressors: In these devices, the energy balance equation helps determine the work output or input required.

- Heat Exchangers: Energy balance is used to analyze the heat transfer between different fluid streams without any work interaction.

-Nozzles and Diffusers: These are devices where kinetic energy changes are significant, and energy balance helps in predicting the exit velocity of the fluid.

Steady Flow Process Assumptions

In steady flow systems, the following assumptions are typically made to simplify the analysis:

- The flow is steady, meaning all properties are constant with time at any given location.

- The mass flow rate is constant.

- The changes in kinetic and potential energy are often small and can be neglected, depending on the specific application.

- The process is adiabatic if heat transfer is negligible, and isentropic if the process is both adiabatic and reversible.

Conclusion

Energy balance in thermodynamics is an essential principle for analyzing both closed and steady flow systems. By understanding and applying the first law of thermodynamics, engineers can design and optimize various thermal systems, ensuring energy efficiency and performance. The careful consideration of heat, work, and internal energy interactions allows for accurate predictions of system behavior under different operating conditions.