Open Systems in Thermodynamics

Introduction

An **open system** in thermodynamics is a system where *mass can cross the boundary*, along with energy in the form of heat or work. Open systems are key for analyzing flow processes, turbines, pumps, nozzles, and chemical reactors.

Key Concepts

- The First Law for Open Systems
- Enthalpy
- Efficiency

Definitions

- **Open System:** A system where both mass and energy may cross the system boundary.
- **Work (W):** Energy transfer associated with a force acting through a distance. Includes flow work.
- **Heat (Q):** Energy transfer due to temperature difference.
- **Enthalpy (H):** Energy required to both create a system and allow it to occupy its volume. Defined as $H = U + PV$.

The First Law for Open Systems

For a system at steady state, we will usually write the energy balance as:

$$\dot{Q} + \dot{W}_{shaft} = \sum_{\text{out}} \dot{m} \left(h + \frac{V^2}{2} + gz \right) - \sum_{\text{in}} \dot{m} \left(h + \frac{V^2}{2} + gz \right)$$

where:

- h: specific enthalpy ($h = u + Pv$)
- V: flow velocity
- gz: gravitational potential energy
- $\dot{W}_{shaft}$: shaft work
- $\dot{Q}$: heat transfer rate

For steady, single-inlet single-outlet systems, it simplifies to:

$$\Delta h + \Delta \left(\frac{V^2}{2} \right) + g\Delta z = \frac{\dot{Q} - \dot{W}_{shaft}}{\dot{m}}$$

However, usually we are able to neglect the velocity and height changes so we are left with:

$$\Delta h = \frac{\dot{Q} - \dot{W}}{\dot{m}}$$

Energies in Open Systems

(i) **Internal Energy (u)**

- Microscopic energy of molecules.
- Directly related to C_v.

(ii) **Kinetic Energy**

- Often negligible, unless flows are fast.
- $KE = \frac{V^2}{2}$

(iii) **Potential Energy**

- Usually neglected unless dealing with pumps or large height differences.
- $PE = gz$

(iv) **Enthalpy (h)**

- Accounts for internal energy and flow work: $h = u + Pv$.
- Fundamental for open system energy balances. It wasn't important for closed systems, but you need to pay attention to it now.

Efficiency

Just like closed systems, efficiency is defined as:

$$\eta = \frac{\text{Actual work output}}{\text{Ideal (reversible) work output}}$$

Example Problem

A turbine receives steam at 3 MPa, 400ºC, and 50 kg/s, and discharges at 0.1 MPa and 100ºC. Assuming negligible kinetic and potential energy changes:

1. Write the energy balance.
$$\dot{W}_{shaft} = \dot{m}(h_{in} - h_{out}) + \dot{Q}$$
2. Assume adiabatic operation ($\dot{Q} = 0$). Solve for the shaft work.
$$\dot{W}_{shaft} = \dot{m}(h_{in} - h_{out})$$

Recap

Open systems allow mass and energy to cross boundaries. Enthalpy replaces internal energy as the key property. Energy balances for steady flow rely on $\dot{Q}$, $\dot{W}$, and the specific energies of entering and exiting streams. Understanding these principles is essential for turbines, pumps, compressors, and flow reactors.