Macroscopic Conservation Laws

Introduction

Macroscopic systems are governed by the fundamental conservation laws of **mass, momentum, and energy**. These laws describe how a system evolves and interacts with its surroundings. They are the backbone of fluid mechanics, thermodynamics, and mechanical engineering. When we do something macroscopically, we're essentially ignoring anything happening on the inside of our system.

Key Concepts

- Mass Balances
- Momentum Balances
- Energy Balances

Definitions

- **Control Volume:** A defined region in space through which mass and energy may flow.
- **Momentum:** Mass times velocity; the quantity of motion of a system.
- **Energy:** The capacity to do work; includes internal, kinetic, and potential energy.

Mass Conservation

The **mass balance** states that mass can neither be created nor destroyed. Using this, we're able to derive relationships to find velocities and mass flowrates for a control volume:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

Momentum Conservation

The **momentum equation** balances the rate of change of momentum with the applied forces:

$$\sum \dot{m}\mathbf{v}_{out} - \sum \dot{m}\mathbf{v}_{in} = \sum \mathbf{F}$$

The right hand side is usually a collection of forces, you can split it into:

$$\sum F = F_{gravity} + F_{pressure} + F_{external}$$

Usually, you will be trying to find F_{ext} which is usually the force required to keep a pipe or assembly in place. Keep this in mind; when dealing with momentum balances, you **must** do balances in their respective directions. ie. flow rates in the x direction, are accounted for in an x direction momentum balance.

Energy Conservation

The **energy balance** accounts for heat, work, and energy carried by mass flow:

$$\hat{W} = \Delta\left(\frac{P}{\rho}\right) + g\Delta z + \frac{(v_2^2 - v_1^2)}{2} + h_f$$

Where h_f is your friction factor, we'll talk about that in a separate guide. Usually you'll be calculating that, or something related to work, like power (work over time).

Recap

The three macroscopic conservation laws describe the flow of mass, momentum, and energy through a system:

- **Mass:** accumulation equals inflow minus outflow.
- **Momentum:** net force equals rate of momentum change.
- **Energy:** energy in plus work/heat equals rate of energy accumulation.

These laws are universal: every fluid flow, mechanical system, or energy transfer process obeys them.