Ninevah University
College of Electronics Engineering
Systems & Control Engineering

1st Law of Thermodynamics Applied to Control Volume

For ***closed systems,*** the mass of the system remains constant during a process.

For ***control volumes,*** mass can cross the boundaries and therefore we must know the amount of mass entering and leaving the system.

Flow Rate

Mass flow rate ($\dot{m}$): The amount of mass flowing through a system per unit time.

$\dot{m} = p\, V_{avg}\, A$ (kg/s)

Volume flow rate (Q): The volume of the fluid flowing through a system per unit.

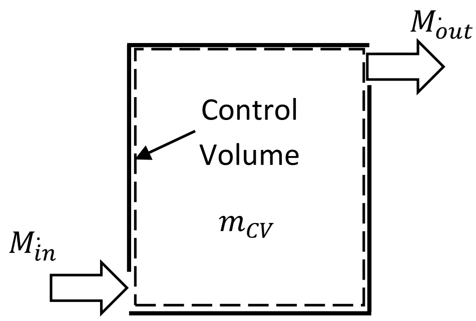
$Q = V_{avg}\, A$ (m^3/s)

Conservation of Mass Principle

$$\begin{pmatrix}\text{Total mass entering} \\ \text{the CV during } \Delta t\end{pmatrix} - \begin{pmatrix}\text{Total mass leaving} \\ \text{the CV during } \Delta t\end{pmatrix} = \begin{pmatrix}\text{Net change of mass} \\ \text{within the CV during } \Delta t\end{pmatrix}$$

In ***rate form:***

$$\dot{M}_{in} - \dot{M}_{out} = \frac{dm_{CV}}{dt}$$

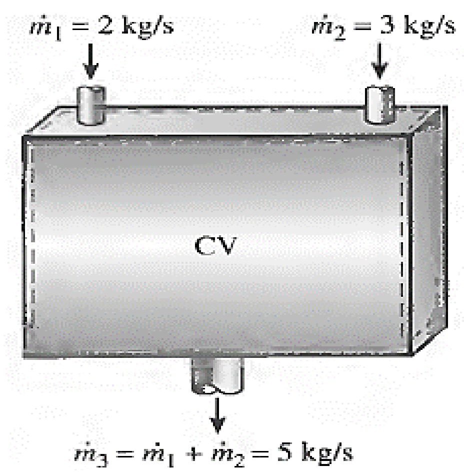


Mass Balance for Steady-Flow Processes

During a **steady-flow** process, the total **amount of mass** within a control volume does not change with time (mcv = constant). Therefore, the total rate of mass **entering** a control volume equal the total rate of mass **leaving** it.

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \qquad \text{(kg/s)}$$

Thus, during a steady-flow process, no property ***within the control volume*** changes with time.

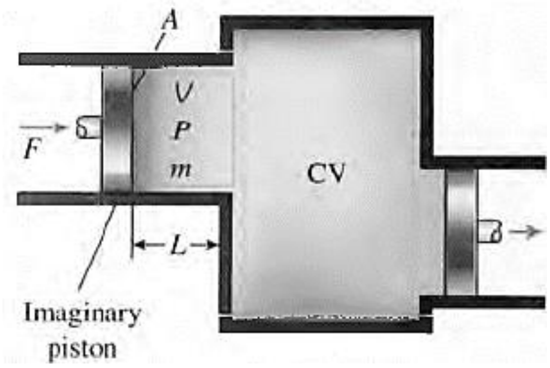


Flow Work

Unlike closed systems, **control volumes** involve mass flow across their boundaries, and some **work** is required to push the mass into or out of the control volume.

To obtain a relation for flow work, consider a fluid element of volume ***V.***

$$W_{flow} = Force\ x\ distance = FL = PA\,L = PV\ (KJ)$$



Total Energy of a Flowing Fluid

The total energy of a close system consists of three parts: internal, kinetic and potential energies. However, for a control volume the system has an additional form of energy that is ***flow energy (PV).*** Then the total energy of a flowing fluid on a unit-mass basis is

$$e = Pv + u + \frac{V^2}{2} + gz$$

The combination ***P v*** + ***u*** is defined as the enthalpy ***h.*** So the relation reduces to

$$e = h + \frac{V^2}{2} + gz\ (\frac{KJ}{Kg}), \qquad where\ h = C_p\ \Delta T$$

It is important to know that ***Cv*** and ***Cp*** depend on temperature. That is, the energy required to raise the temperature of a substance by one degree is different at different temperatures. But this difference is usually not very large and can be neglected.

The total amount of energy transport is

$$E = m\,e = m\left(h + \frac{V^2}{2} + gz\right)\ (KJ)$$

The rate of energy transport

$$E^{\cdot} = \frac{E}{t} = m^{\cdot}\left(h + \frac{V^2}{2} + gz\right)(KW)$$

When the kinetic and potential energies of a fluid stream are negligible, these relations simplify to

E = ***mh***

E˙= ***m˙h***

Energy Analysis of Steady-Flow Systems

During a steady-flow process, the total **energy content** of a control volume remains constant. Therefore, the rate of energy entering a control volume in all forms (by heat, work, and mass) must be equal to the rate of energy leaving it.

Rate of net energy transfer in by = Rate of net energy transfer out by

Heat, work and mass　　　　　　　Heat, work and mass

$$\dot{E_{in}} = \dot{E_{out}}$$

$$\dot{Q_{in}} + \dot{W_{in}} + \underbrace{\sum_{in} \dot{m} \left(h + \frac{V^2}{2} + gz\right)}_{\textit{For each input}} = \dot{Q_{out}} + \dot{W_{out}} + \underbrace{\sum_{out} \dot{m} \ (h + \frac{V^2}{2} + gz)}_{\textit{For each output}}$$

The first-law of thermodynamic for a general steady-flow system becomes

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

$$\boxed{\dot{Q} - \dot{W} = \dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(Z_2 - Z_1)\right)}$$

$\dot{Q}$: Rate of heat transfer between the control volume and its surroundings.

$\dot{W} : Power$

Dividing the equation above by $\dot{m}$ gives the energy balance on a unit-mass:

$$\boxed{q - w = \left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(Z_2 - Z_1)\right)}$$

q and w: are the heat transfer and work done per unit mass of the working fluid.

in practice, the kinetic and potential energies **are very small** compared with the enthalpy. When the fluid experiences negligible changes in its kinetic and potential energies (that is, Δke = 0, Δpe = 0),

$$\boxed{q - w = \Delta h}$$