ESO 201A: Thermodynamics

2016-2017-I semester

Mass-Energy Analysis: part 1

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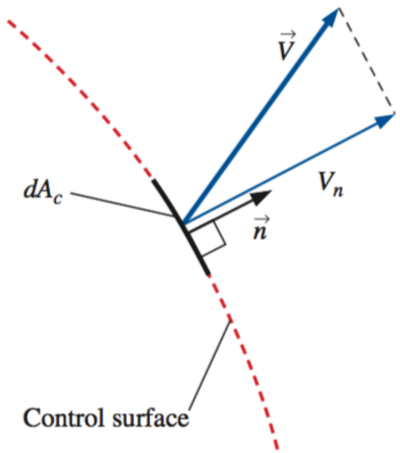
Learning objectives

- Develop the conservation of mass principle.
- Apply the conservation of mass principle to various systems including steady- and unsteady-flow control volumes.
- Apply the first law of thermodynamics as the statement of the conservation of energy principle to control volumes.
- Identify the energy carried by a fluid stream crossing a control surface as the sum of internal energy, flow work, kinetic energy, and potential energy of the fluid and to relate the combination of the internal energy and the flow work to the property enthalpy.
- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, heaters, and heat exchangers.
- Apply the energy balance to general unsteady-flow processes with particular emphasis on the uniform-flow process as the model for commonly encountered charging and discharging processes.

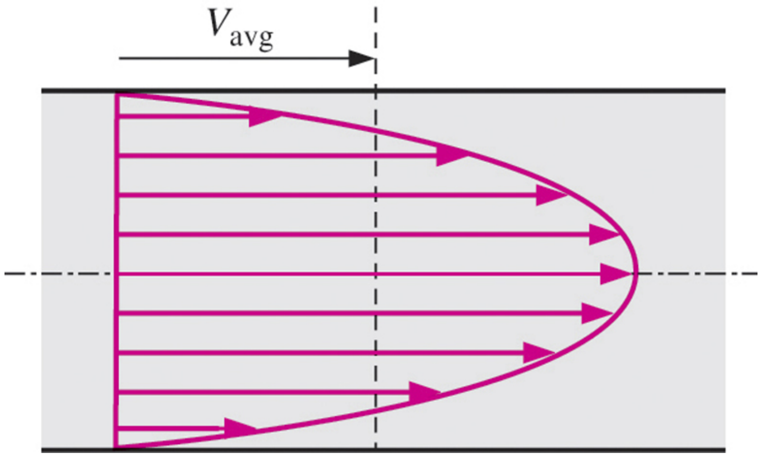
Mass and volume flow rate



$$\delta \dot{m} = \rho V_n \, dA_c$$

$$\dot{m} = \int_{A_c} \delta \dot{m} = \int_{A_c} \rho V_n \, dA_c$$

$$V_{avg} = \frac{1}{A_c} \int_{A_c} V_n \, dA_c$$ Definition of average velocity



$$\dot{m} = \rho V_{avg} A_c \qquad (\mathrm{kg/s})$$

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{v}$$ Mass flow rate

The average velocity V_{avg} is defined as the average speed through a cross section.

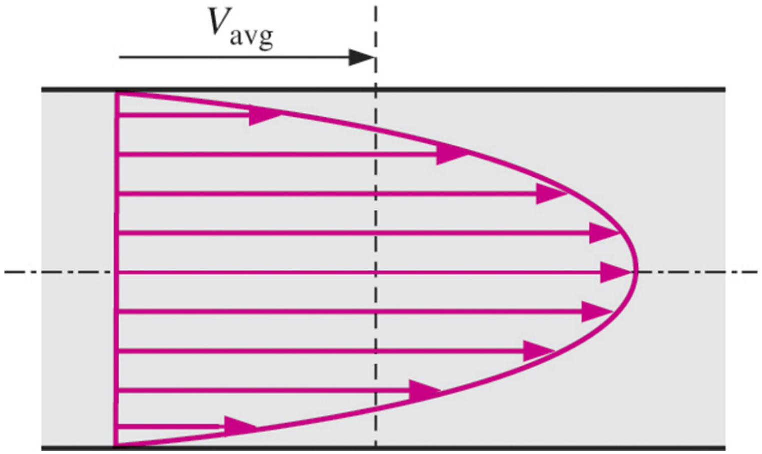
Mass and volume flow rate

$$\dot{m} = \rho V_{\text{avg}} A_c \qquad \text{(kg/s)}$$

$$\dot{V} = \int_{A_c} V_n \, dA_c = V_{\text{avg}} A_c = V A_c \qquad (\text{m}^3/\text{s})$$

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{v}$$

Mass flow rate



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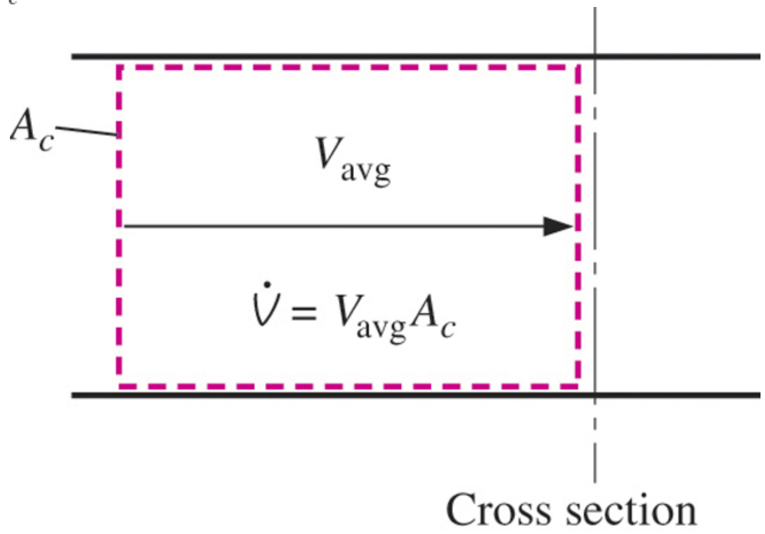
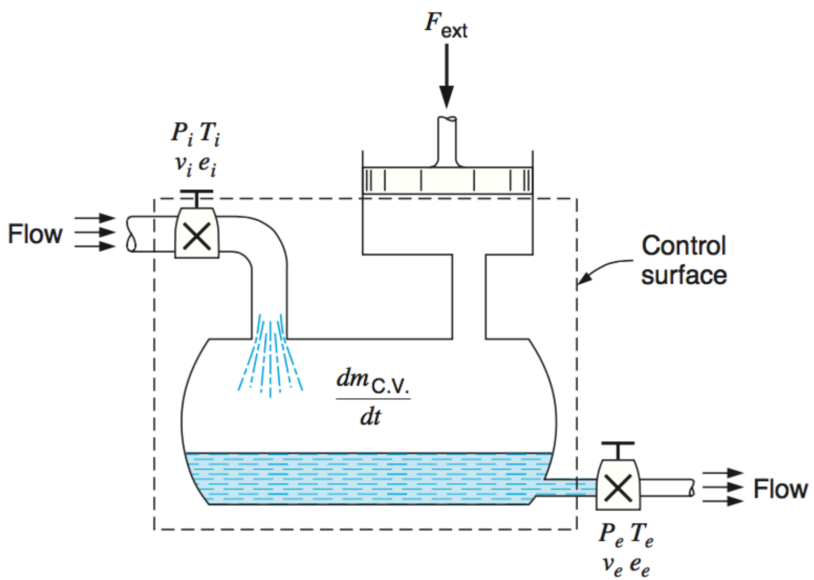


The volume flow rate is the volume of fluid flowing through a cross section per unit time.

Conservation of mass principle

The conservation of mass principle for a control volume: The net mass transfer to or from a control volume during a time interval Δt is equal to the net change (increase or decrease) in the total mass within the control volume during Δt.

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



$$m_{in} - m_{out} = \Delta m_{CV} \qquad \text{(kg)}$$

$$\dot{m}_{in} - \dot{m}_{out} = dm_{CV}/dt \qquad \text{(kg/s)}$$

Conservation of mass principle

General conservation of mass

$$\frac{d}{dt}\int_{\mathrm{CV}} \rho \, dV + \int_{\mathrm{CS}} \rho(\vec{V}\cdot\vec{n})\, dA = 0$$

General conservation of mass in rate form

$$\frac{d}{dt}\int_{\mathrm{CV}} \rho \, dV = \sum_{\mathrm{in}} \dot{m} - \sum_{\mathrm{out}} \dot{m}$$

or $$\frac{dm_{\mathrm{CV}}}{dt} = \sum_{\mathrm{in}} \dot{m} - \sum_{\mathrm{out}} \dot{m}$$

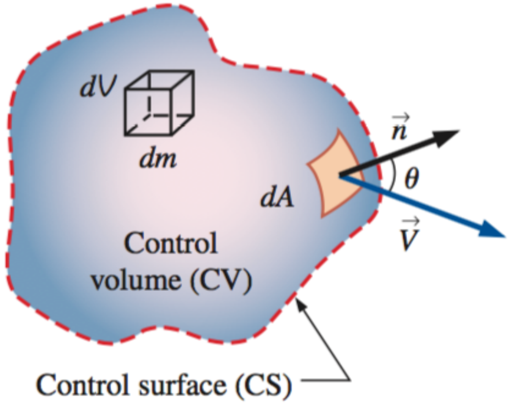
Conservation of mass principle

Total mass within the CV

$$m_{CV} = \int_{CV} \rho \, dV$$

Rate of change of mass with the CV

$$\frac{dm_{CV}}{dt} = \frac{d}{dt}\int_{CV} \rho \, dV$$



Differential mass flow rate: $\delta \dot{m} = \rho V_n \, dA = \rho(V\cos\theta)\, dA = \rho(\vec{V}\cdot\vec{n})\, dA$

Net mass flow rate: $$\dot{m}_{net} = \int_{CS} \delta \dot{m} = \int_{CS} \rho V_n \, dA = \int_{CS} \rho(\vec{V}\cdot\vec{n})\, dA$$

Direction is accounted.

$\dot{m}_{in} - \dot{m}_{out} = dm_{CV}/dt$ (kg/s) Can be written as

General conservation of mass: $$\frac{d}{dt}\int_{CV} \rho \, dV + \int_{CS} \rho(\vec{V}\cdot\vec{n})\, dA = 0$$

Conservation of mass principle

$$\frac{d}{dt}\int_{CV} \rho \, dV + \sum_{out} \rho |V_n| A - \sum_{in} \rho |V_n| A = 0$$

$$\frac{d}{dt}\int_{CV} \rho \, dV = \sum_{in} \dot{m} - \sum_{out} \dot{m} \quad \text{or} \quad \frac{dm_{CV}}{dt} = \sum_{in} \dot{m} - \sum_{out} \dot{m}$$

Mass balance for steady-flow process

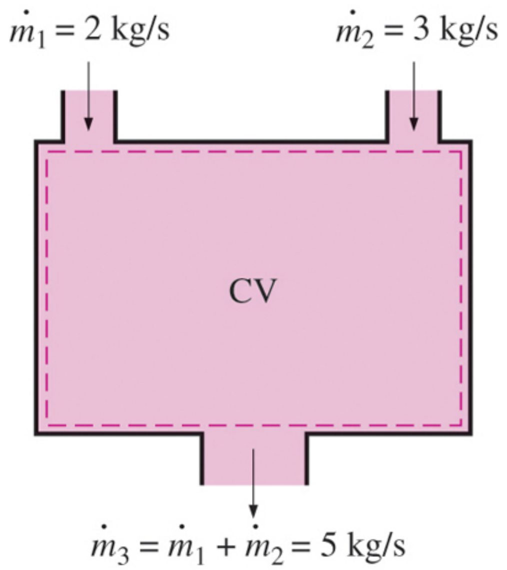
During a steady-flow process, the total amount of mass contained within a control volume does not change with time (m_{CV} = constant).

Then the conservation of mass principle requires that the total amount of mass entering a control volume equal the total amount of mass leaving it.

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

Multiple inlets and exits

Mass balance for steady-flow process

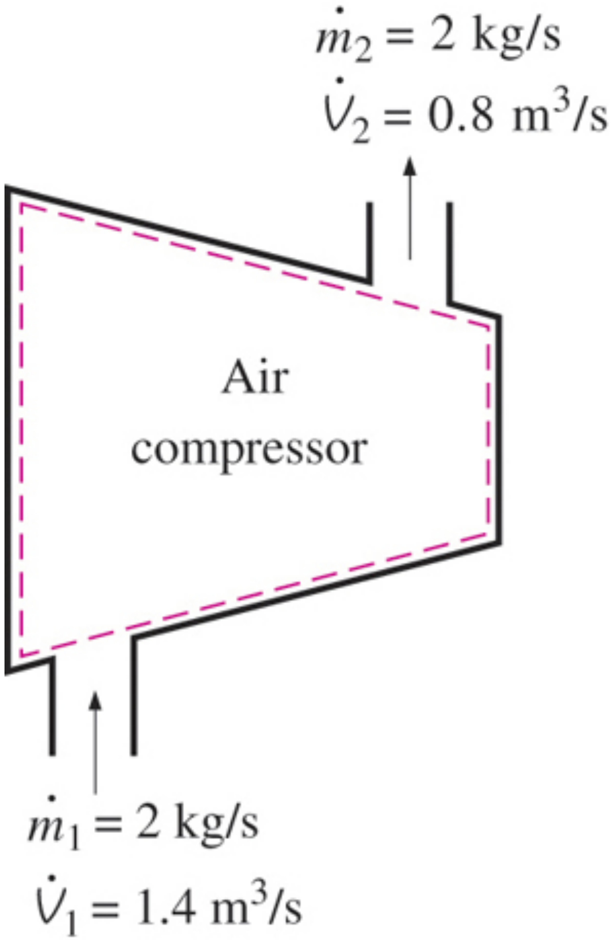


Many engineering devices such as nozzles, diffusers, turbines, compressors, and pumps involve a single stream (only one inlet and one outlet).

$$\dot{m}_1 = \dot{m}_2 \quad \rightarrow \quad \rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

Single stream

Incompressible fluid



$$\sum_{\text{in}} \dot{V} = \sum_{\text{out}} \dot{V} \quad (\text{m}^3/\text{s})$$

Steady, incompressible

$$\dot{V}_1 = \dot{V}_2 \rightarrow V_1 A_1 = V_2 A_2$$

Steady, incompressibl e flow (single stream)

Note: during a steady-flow process, volume flow rates are not necessarily conserved although mass flow rates are.

Next lecture

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