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Module

4

Lecture
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Asansol Engineering College
Department of Mechanical Engineering

TECHNO INDIA GROUP

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Thermodynamics

First Law for Flow Processes

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ENERGY BALANCE FOR STEADY-FLOW SYSTEMS

- A large number of engineering devices such as *turbines, compressors, and nozzles* operate for long periods of time under the same conditions once the transient start-up period is completed and steady operation is established, and they are classified as *steady-flow devices*.

- Processes involving such devices can be represented reasonably well by a somewhat idealized process, called the *steady-flow process*,

- *Steady flow process* can be defined as *a process during which a fluid flows through a control volume steadily.* That is, the fluid properties can change from point to point within the control volume, but at any point, they remain constant during the entire process.

- During a steady-flow process, the total energy content of a control volume remains constant (E_{CV} = constant), and thus the change in the total energy of the control volume is zero (ΔE_{CV} =0).
- Therefore, the amount of energy entering a control volume in all forms (by heat, work, and mass) must be equal to the amount of energy leaving it. Then the rate form of the general energy balance reduces for a steady-flow process to

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}} \xrightarrow{} 0 \text{ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

or

Energy balance:

$$\underbrace{\dot{E}_{\text{in}}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat, work, and mass}}} = \underbrace{\dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer out} \\ \text{by heat, work, and mass}}}$$

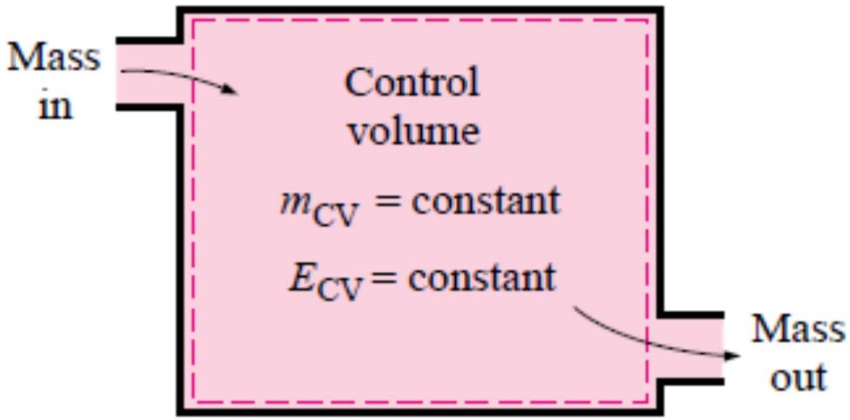


Fig. 4.3: Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

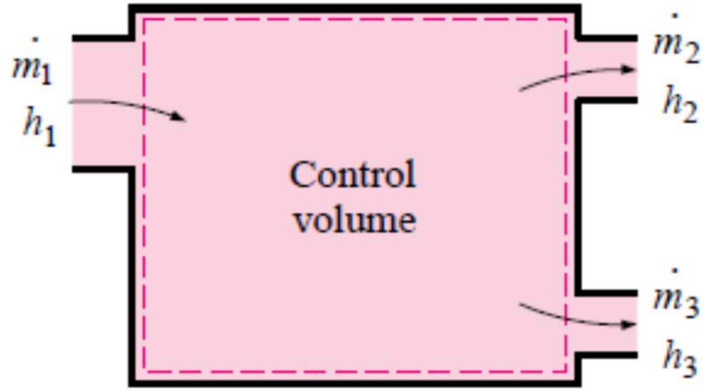


Fig. 4.4: Under steady-flow conditions, the fluid properties at an inlet or exit remain constant (do not change with time).

Then, the energy can be transferred by heat, work, and mass only, the energy balance for a general steady-flow system can also be written as

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_{in}\,\theta_{in} = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}\,\theta_{out}$$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz) = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}\,(h + \frac{v^2}{2} + gz)$$

Consider the mass flow rate through the entire control volume remains constant $(\dot{m}_{in} = \dot{m}_{out} = \dot{m})$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \qquad (h + \frac{v^2}{2} + gz) = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}\,(h + \frac{v^2}{2} + gz)$$

$$\dot{q}_{in} + \dot{w}_{in} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz) = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}\,(h + \frac{v^2}{2} + gz)$$

Mass Balance

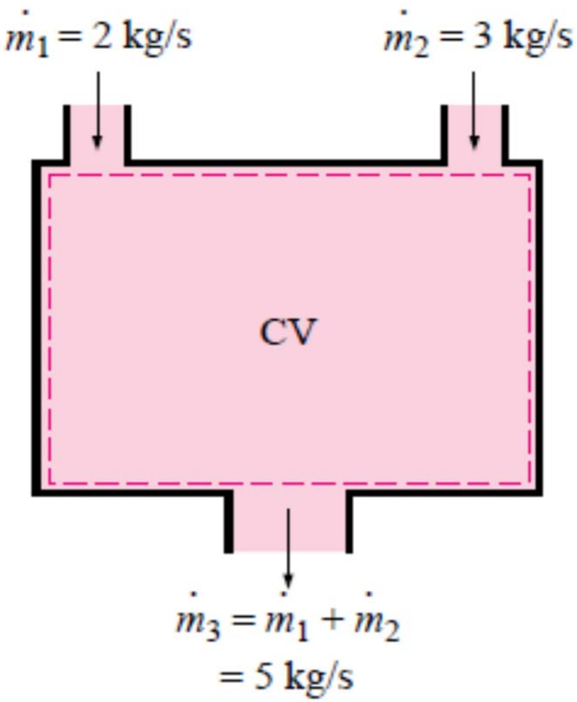


Fig. 4.5: Conservation of mass principle for a two-inlet–one-exit steady-flow system.

The *mass balance* for a general steady-flow system can be expressed in the rate form as

Mass balance for steady-flow systems: $$\dot{m}_{in} = \dot{m}_{out} \quad \text{(kg/s)}$$

It can also be expressed for a steady-flow system with multiple inlets and exits as

Multiple inlets and exits: $$\sum \dot{m}_i = \sum \dot{m}_e \quad \text{(kg/s)}$$

- Most engineering devices such as *nozzles, diffusers, turbines, compressors, and pumps* involve a single stream (one inlet and one exit only).
- For these cases, we denote the inlet state by the subscript 1 and the exit state by the subscript 2, and drop the summation signs. Then the mass balance for a single stream steady-flow system becomes

One inlet and one exit:

$$\dot{m}_1 = \dot{m}_2$$

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

where ρ is density, v is the average flow velocity in the flow direction, and A is the cross-sectional area normal to the flow direction.

Nozzles and Diffusers

- A *nozzle* is a steady-state device whose purpose is to create a high-velocity fluid stream at the expense of the fluid pressure.
- It is contoured in an appropriate manner to expand a flowing fluid smoothly to a lower pressure, thereby increasing its velocity.

- A *diffuser* is a device that increases the pressure of a fluid by slowing it down.

- That is, nozzles and diffusers perform opposite tasks.

- Nozzles and diffusers are commonly utilized in *jet engines, rockets, spacecraft, and even garden hoses.*

Nozzles and Diffusers (*Contd…*)

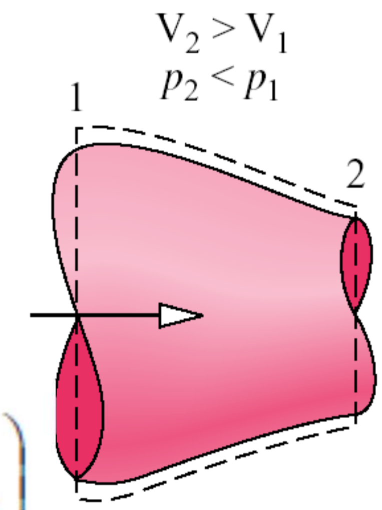
Assumptions: (1) adiabatic, Q = 0
(2) no volume changes, W = 0
(3) steady-state, d/dt = 0
(4) change in potential energy negligible

$$\cancel{\frac{dE_{cv}}{dt}} = \cancel{\dot{Q}} - \cancel{\dot{W}} + \sum \dot{m}_{in}\left(h_{in} + \frac{V_{in}^2}{2} + \cancel{gz_{in}}\right) - \sum \dot{m}_{out}\left(h_{out} + \frac{V_{out}^2}{2} + \cancel{gz_{out}}\right)$$

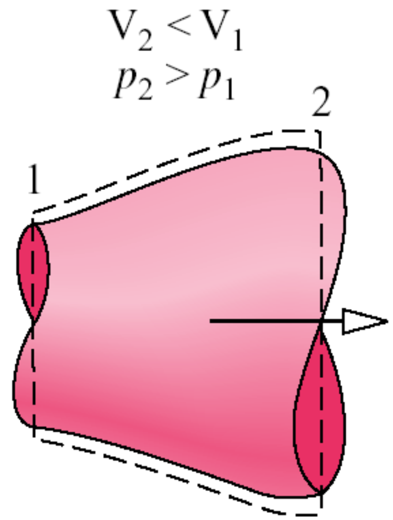
$$\boxed{h_{in} + \frac{V_{in}^2}{2} = h_{out} + \frac{V_{out}^2}{2}}$$

or

$$\boxed{\Delta h = h_{out} - h_{in} = \frac{V_{in}^2}{2} - \frac{V_{out}^2}{2}}$$



Nozzle



Diffuser

Nozzles and Diffusers

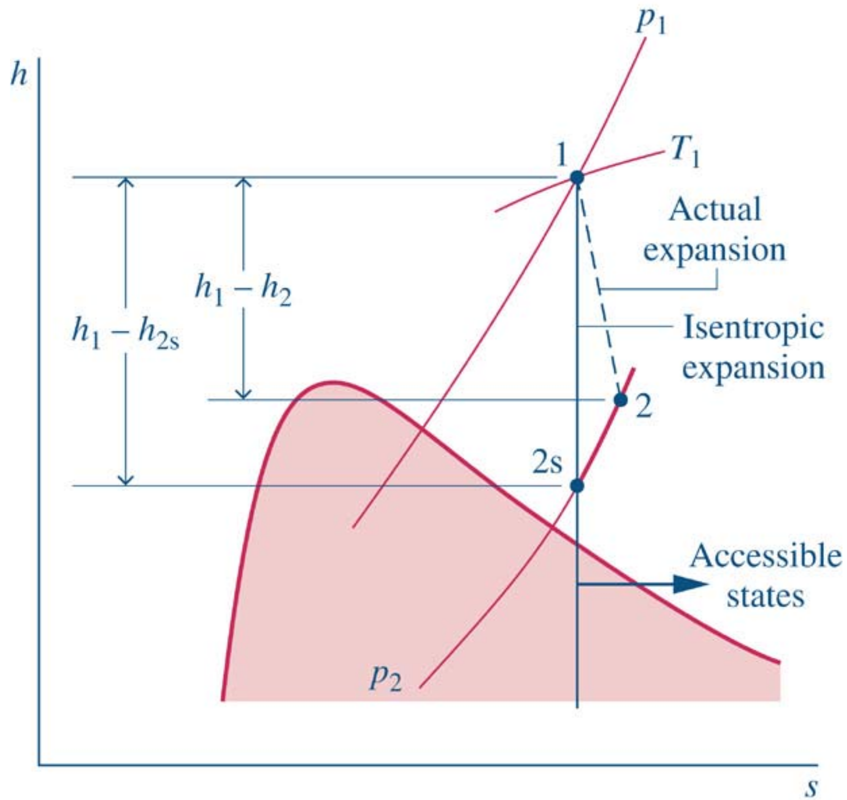


Fig. 4.6: h-s diagram for Nozzle

Nozzle Efficiency:

Compares the performance of a actual nozzle or diffuser to the performance of an ideal, isentropic nozzle or diffuser operating *between the same pressures*

$$\eta_{nozzle} = \frac{\Delta h_{actual}}{\Delta h_{ideal}} = \frac{\left(V_{outlet}^2 - V_{inlet}^2\right)/2}{\left(V_{outlet,s}^2 - V_{inlet}^2\right)/2}$$

Actual process

Isentropic process with same initial state and final pressure

Solved Examples

Example 4.1.

Steam at 0.6 MPa and 200◦C enters an insulated nozzle with a velocity of 50 m/s. It leaves at a pressure of 0.15 MPa and a velocity of 600 m/s. Determine the final temperature if the steam is superheated in the final state and the quality if it is saturated.

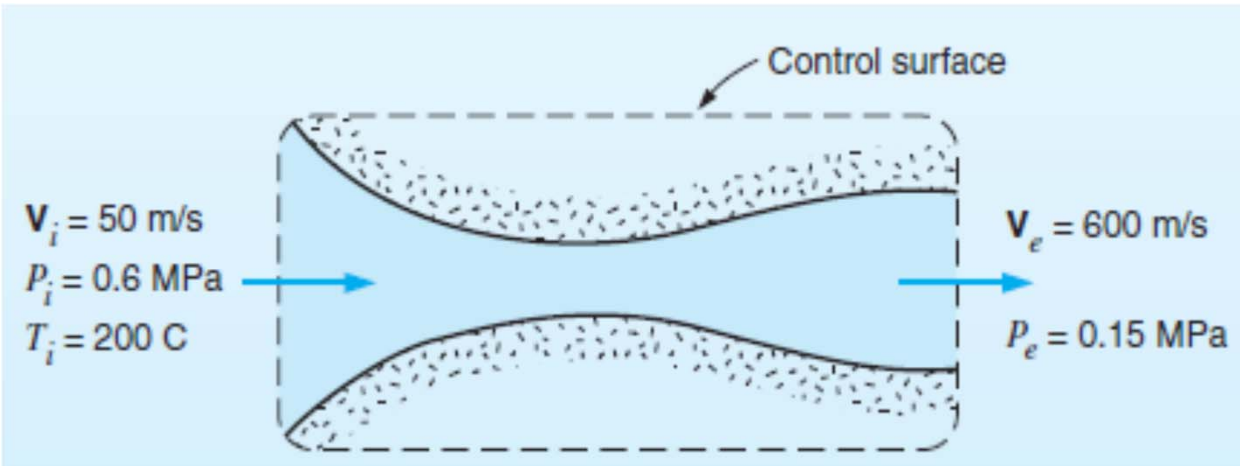


Fig. 4.7: Nozzle

Analysis:

$\dot{Q}_{C.V.} = 0$ (nozzle insulated)

$\dot{W}_{C.V.} = 0$

$PE_i \approx PE_e$

Solution:

Energy Balance Equation

$$h_{in} + \frac{V_{in}^2}{2} = h_{out} + \frac{V_{out}^2}{2}$$

$$h_{out} = h_{in} + \left(\frac{V_{in}^2}{2} - \frac{V_{out}^2}{2} \right)$$

$$h_{out} = 2850.1 + \left(\frac{50 \times 50}{2 \times 1000} - \frac{600 \times 600}{2 \times 1000} \right) = 2671.4 \text{kJ/kg}$$

The two properties of the fluid leaving that we now know are pressure and enthalpy, and therefore the state of this fluid is determined. Since h_e is less than h_g at 0.15 MPa, the quality is calculated.

$$h = h_f + xh_{fg} = h_f + x(h_g - h_f)$$

$$2671.4 = 467.1 + x2226.5$$

$$x = 0.99$$

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Thank You