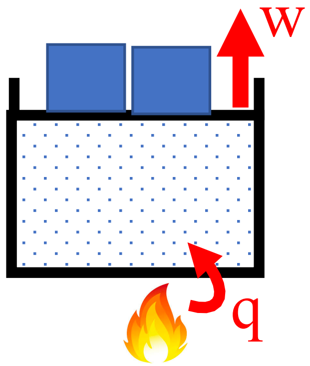
1^{st} law for open system

CLOSED SYSTEM:



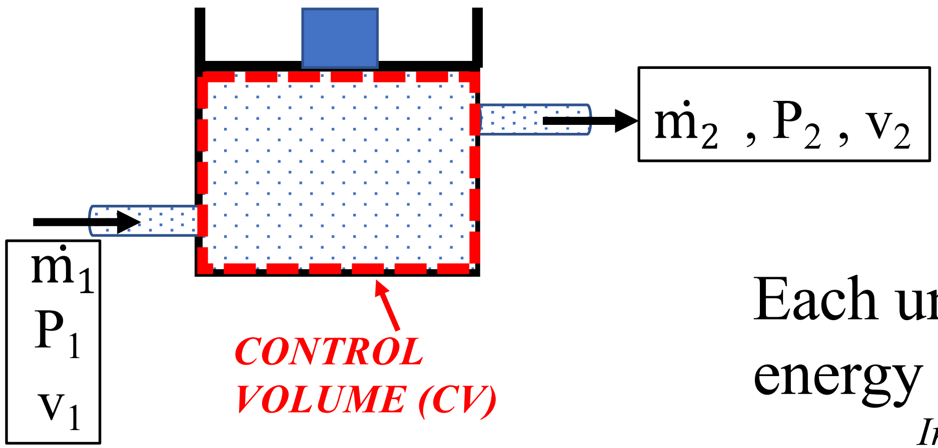
$$\Delta U = q + w$$ **(First law)**

Change with respect to time

$$\frac{\Delta U}{t} = \frac{q}{t} + \frac{w}{t} \quad (t = \text{time})$$

$$\Rightarrow \Delta \dot{U} = \dot{q} + \dot{w}$$

OPEN SYSTEM:



1st Law open system

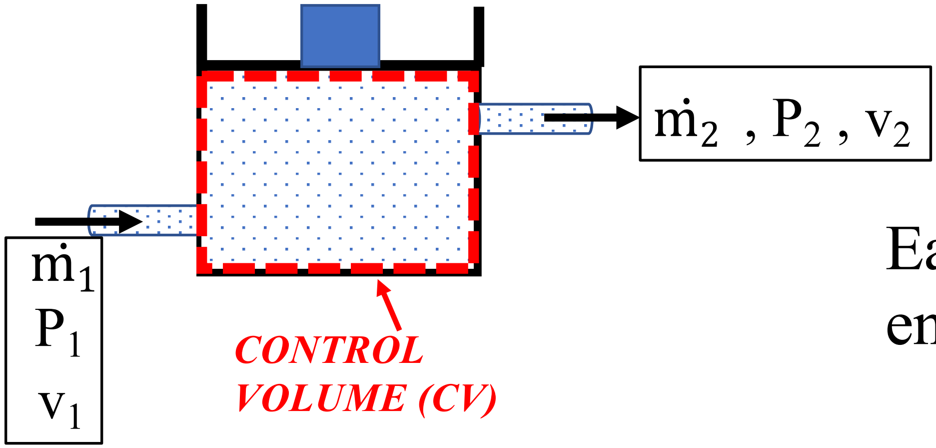
$$\Rightarrow \Delta \dot{U} = \dot{q} + \dot{w} + \frac{d}{dt}$$ [*Stream flow energy*]

Each unit of stream carries with a total energy $= u + \frac{1}{2} v^2 + z\,g$

Internal energy (u), *Kinetic energy* ($\frac{1}{2} v^2$), *Potential energy* ($z\,g$)

v = velocity
z = elevation from the ground
g = gravitational acceleration

OPEN SYSTEM:



1st Law open system

$$=)\ \Delta \dot{U}_{CV} = \dot{q} + \dot{w} + \frac{d}{dt}\ [\textit{Stream flow energy}]$$

Each unit of stream carries with a total energy $= u + \frac{1}{2} v^2 + z\,g$

Internal energy *Kinetic energy* *Potential energy*

v = velocity
z = elevation from the ground
g = gravitational acceleration

Thus, stream of mass "m" transport energy as the rate $= \dot{m}\,(u + \frac{1}{2} v^2 + z\,g)$

$$=)\ \Delta \dot{U}_{CV} = \dot{q} + \dot{w} + [\dot{m}_1(u_1 + \tfrac{1}{2} v_1^{\,2} + z_1 g) - \dot{m}_2(u_2 + \tfrac{1}{2} v_2^{\,2} + z_2 g)\ ]$$

Work rate ($\dot{w}$)

$$\dot{w} = \dot{w}_{cv} + \dot{Flow\ work}$$

$$\dot{Flow\,work} = \frac{d}{dt}\,[Force\ x\ distance]$$

$$= \frac{d}{dt}\,[(Force\ /\boldsymbol{Area})\ x\ (\boldsymbol{Area}\ x\ distance)\ ]$$

$$= \frac{d}{dt}\,[Pressure\ x\ Area\ x\ distance]$$

$$= \ Pressure\ x\ Area\ x\ \frac{d}{dt}\,[distance]$$

$$= \ Pressure\ x\ Area\ x\ velocity$$

$$= \mathrm{P\ A\ v}$$

Pressure = P
Area = A
$\frac{d}{dt}\,[distance]$ = velocity = v

density = $\boldsymbol{\rho}$

Now, rate of change of mass (m):

$$\dot{\mathrm{m}} = \frac{dm}{dt} = \frac{d(density\ x\ volume)}{dt} = \frac{d(density\ x\ Area\ x\ distance)}{dt} = \boldsymbol{\rho}\ \mathrm{A\ v}$$

$$\dot{m} = \boldsymbol{\rho}\, A\, v$$

$$\Rightarrow \frac{\dot{m}}{\boldsymbol{\rho}} = A\, v$$

$$\Rightarrow \dot{m}\, \overline{V} = A\, v$$

$\overline{V}$ = Specific volume

$$\dot{Flow\ work} = P \boxed{A\, v} = P \boxed{\dot{m}\, \overline{V}}$$

1st law open system

$$\Delta \dot{U}_{CV} = \dot{q} + \boxed{\dot{w}} + [\dot{m}_1(u_1 + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(u_2 + \tfrac{1}{2} v_2^2 + z_2 g)]$$

$$= \dot{q} + \boxed{\dot{w}_{cv} + \dot{Flow\,work}} + [\dot{m}_1(u_1 + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(u_2 + \tfrac{1}{2} v_2^2 + z_2 g)]$$

$$= \dot{q} + \boxed{\dot{w}_{cv} + (P_1\, \dot{m}_1\, \overline{V_1} - P_2\, \dot{m}_2\, \overline{V_2})} + [\dot{m}_1(u_1 + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(u_2 + \tfrac{1}{2} v_2^2 + z_2 g)]$$

$$= \dot{q} + \dot{w}_{cv} + \dot{m}_1(u_1 + P_1\, \overline{V_1} + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(u_2 + P_2\, \overline{V_2} + \tfrac{1}{2} v_2^2 + z_2\, g)$$

$$= \dot{q} + \dot{w}_{cv} + \dot{m}_1(\overline{H_1} + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(\overline{H_2} + \tfrac{1}{2} v_2^2 + z_2\, g)$$

Mass Balance

Mass of the system within the control volume is constant

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

$$\Delta \dot{U}_{CV} = \dot{q} + \dot{w}_{cv} + \dot{m}_1(\overline{H_1} + \tfrac{1}{2} v_1^2 + z_1 g) - \dot{m}_2(\overline{H_2} + \tfrac{1}{2} v_2^2 + z_2 g)$$

$$\Delta \dot{U}_{CV} = \dot{q} + \dot{w}_{cv} + \dot{m}_1 [(\overline{H_1} + \tfrac{1}{2} v_1^2 + z_1 g) - (\overline{H_2} + \tfrac{1}{2} v_2^2 + z_2 g)]$$

$$\Delta \dot{U}_{CV} = \dot{q} + \dot{w}_{cv} + \dot{m} (\overline{H_1} - \overline{H_2}) + \tfrac{1}{2} \dot{m}(v_1^2 - v_2^2) + \dot{m}(z_1 g - z_2 g)$$

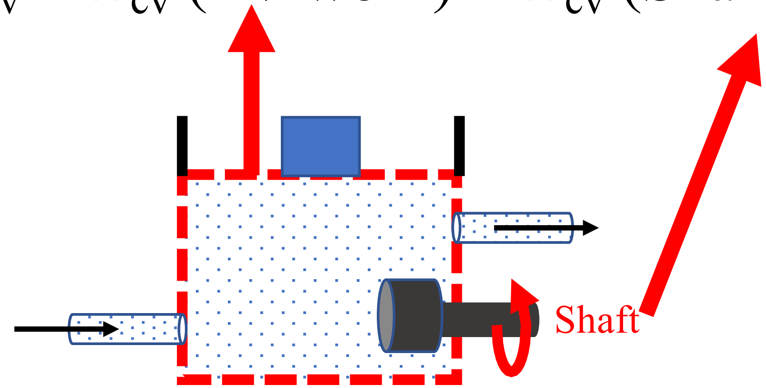
$$\Delta \dot{U}_{CV} = \dot{q} + \dot{w}_{cv} + \dot{m}\, \Delta (\overline{H} + \tfrac{1}{2} v^2 + zg)$$

Steady Flow $\Delta \dot{U}_{CV} = 0$

$$\dot{q} + \dot{w}_{cv} + \dot{m}\, \Delta (\overline{H} + \tfrac{1}{2} v^2 + zg) = 0$$

Work ($\dot{w}_{cv}$)

$$\dot{w}_{cv} = \dot{w}_{cv}\ (\text{PV work}) + \dot{w}_{cv}\ (\text{Shaft work})$$



$$\dot{w}_{cv}\ (\text{Shaft work}) = 2\pi T\,\dot{n}$$

T = Torque n = number of times it rotate/revolutions

Lecture 5

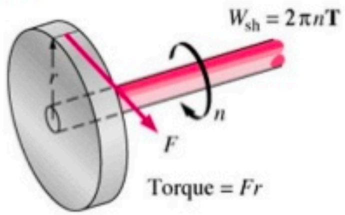
Mechanical Forms of Work
Shaft Work

- A force F acting through a moment arm r generates a torque T of:

$$T = F \times r \quad \rightarrow \quad F = \frac{T}{r}$$

- This force acts through a distance s, which is related to the radius r by: $s = (2\pi r)n$

  where n is the number of revolutions



- The shaft work will be:

$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r n) = 2\pi n T$$

- The power transmitted through the shaft is the shaft work done per unit time:

$$\dot{W}_{sh} = 2\pi \dot{n} T$$

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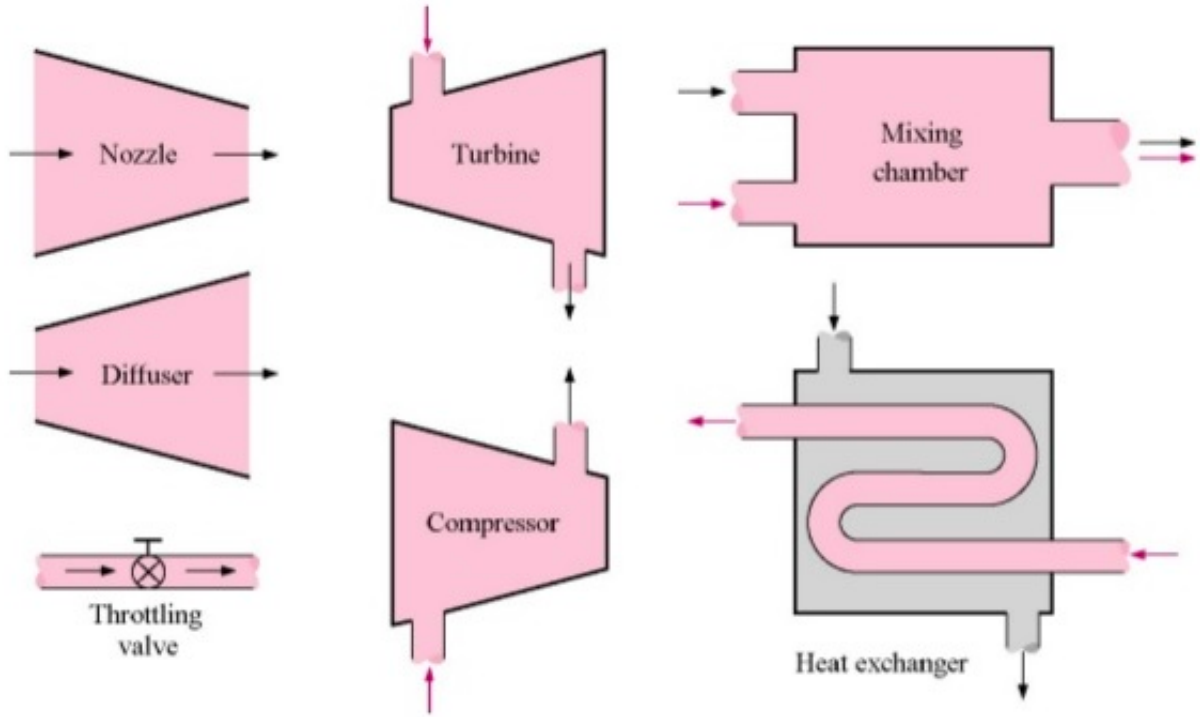
Steady Flow Devices



APPLYING SFEE in STEADY-FLOW SYSTEMS

Nozzles and Diffusers

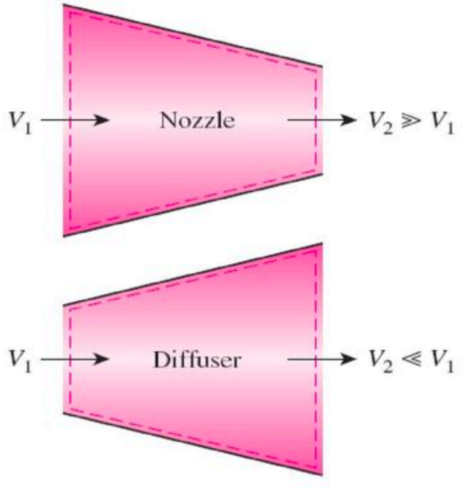


FIGURE 5–25
Nozzles and diffusers are shaped so that they cause large changes in fluid velocities and thus kinetic energies.

Mass balance for a nozzle or diffuser:

$$\dot{m}_i = \dot{m}_e = \dot{m}$$

$$\rho_i A_i V_i = \rho_e A_e V_e$$

Energy balance for a nozzle or diffuser:

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right)$$

(since $\dot{Q} \cong 0$, $\dot{W} = 0$, and $\Delta\text{pe} \cong 0$)

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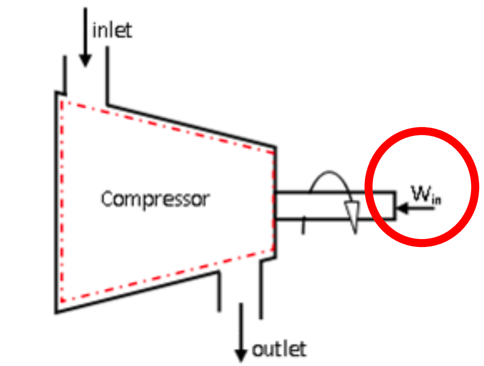
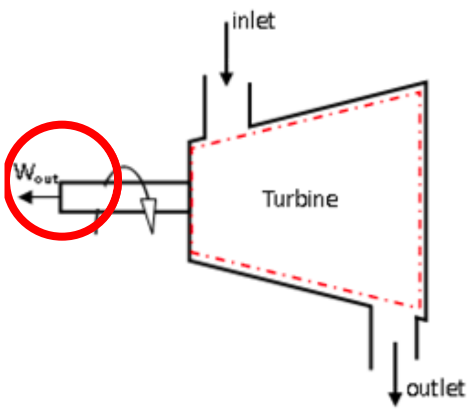




- Compressor/ Turbines are Steady Flow Devices: $\Delta \dot{U}_{CV} = 0$

- Furthermore, $m_{out}=m_{in}$ because of conservation of mass.

$$\dot{q} + \dot{w}_{cv} + \dot{m}\,\Delta\,(\,\overline{H} + \tfrac{1}{2}\,v^2 + zg) = 0$$

- The change of kinetic energy and potential energy of fluid flowing into and out of turbines and compressors are very small that can usually be neglected.

- Well insulated device, $q = 0$

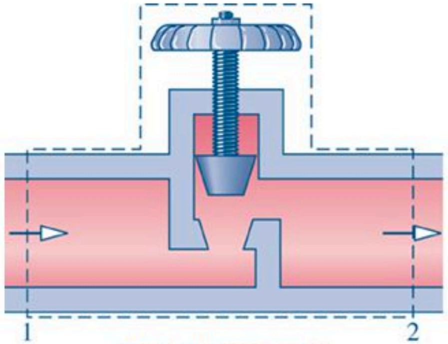
$$\dot{w}_{cv} + \dot{m}\,\Delta\overline{H} = 0$$

$$\mathbf{W_{cv} = m\,(\,\overline{H}_{out} - \overline{H}_{in})}$$

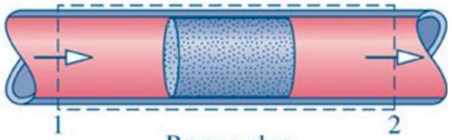
$W_{cv} > 0 \rightarrow$ compressor
$W_{cv} < 0 \rightarrow$ turbine

Throttling devices

Flow restriction



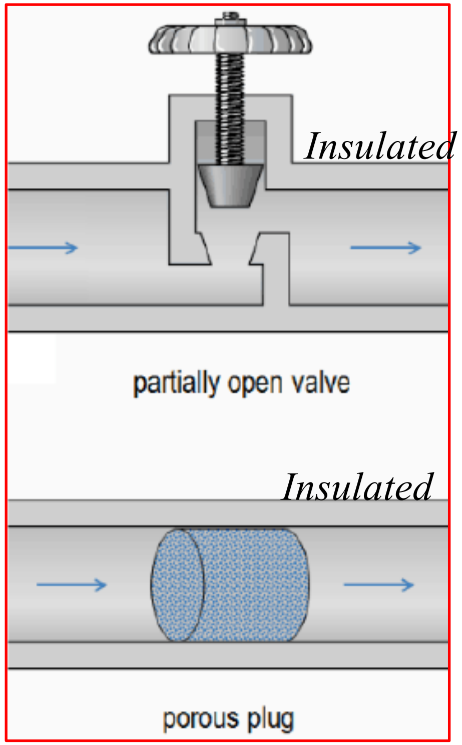
Partially open valve



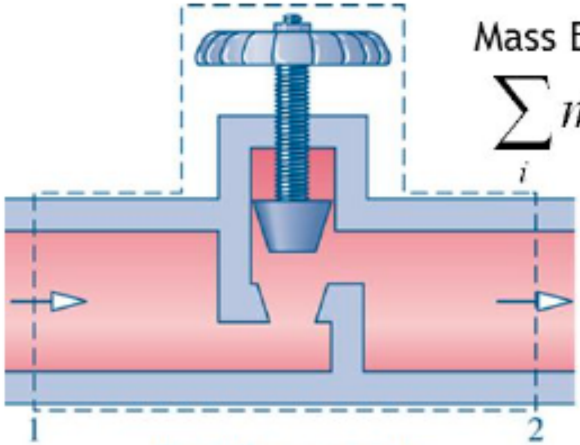
Porous plug

A device that causes a drop in pressure by restricting the flow passage can be termed a throttling device.

Lecture 0



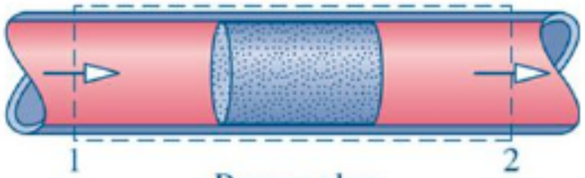
Throttling Device: Reduces Pressure



Partially open valve

Mass Balance:

$$\sum_i \dot{m}_{in} = \sum_i \dot{m}_{exit} \rightarrow \dot{m}_{in} = \dot{m}_{exit} = \dot{m}$$



Porous plug

Typical Energy Balance simplifications,

$$\cancel{\frac{dU_{CV}}{dt}} = \cancel{\dot{Q}_{CV}} + \cancel{\dot{W}_{CV}} + \dot{m}_i\left(h_i + \cancel{\frac{v_i^2}{2}} + \cancel{gz_i}\right) - \dot{m}_e\left(h_e + \cancel{\frac{v_e^2}{2}} + \cancel{gz_e}\right)$$

Steady State

No heat transfer

No work

$\Delta v \approx 0$

Horizontal Section (or very short vertical)

$$h_i = h_e$$

Throttling devices

$$\boxed{H_1 = H_2 \text{ (isoenthalpic)}}$$

Next: Throttling and Joule Thompson effect