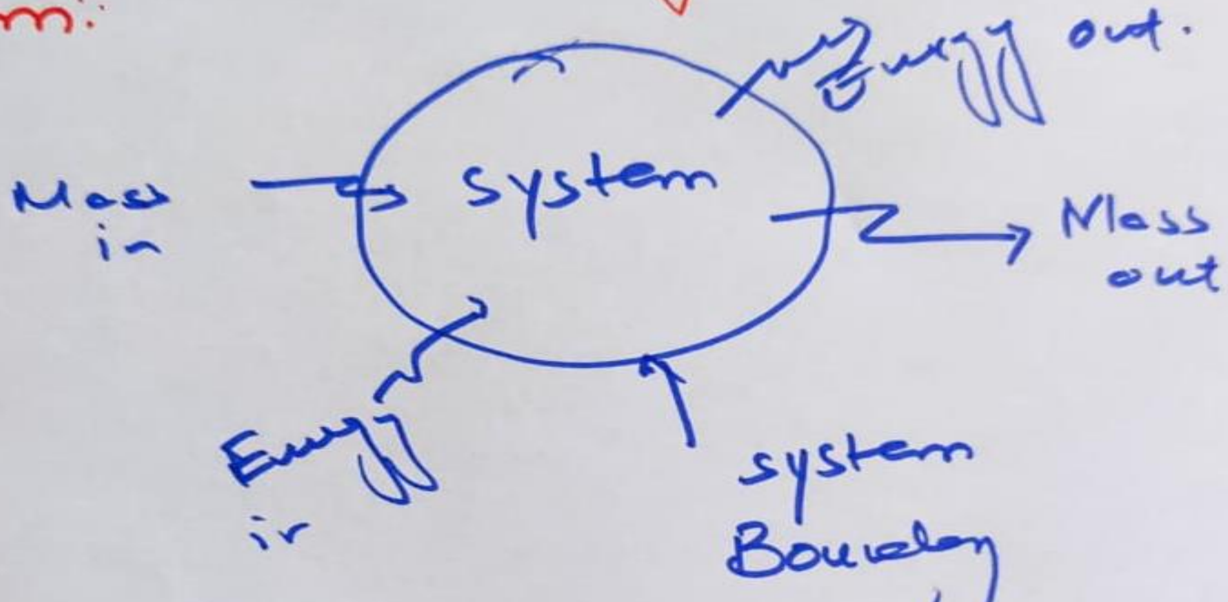
1st Law for Open Systems

First Law of thermodynamics for Open system:



Open system.

Rate of Mass transfer "Mass Flow rate"

Rate of Energy transfer

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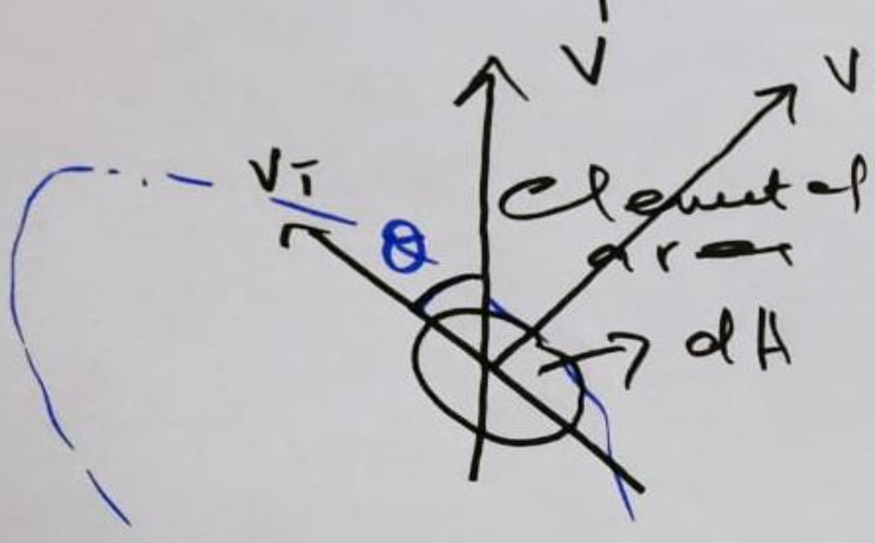
Mass Flow rate:-

Amount of mass flowing through a section per unit time.



V_n = Normal component of velocity

$$dm = \rho \times V_n \times dA$$

mass flow rate is an inexact differential.

Work transfer
Heat transfer
Mass transfer

] Path → Function

$$\int_{m_1}^{m_2} dm = ?\ \times$$

Mass Flow Rate is a path ~~State~~ Function.

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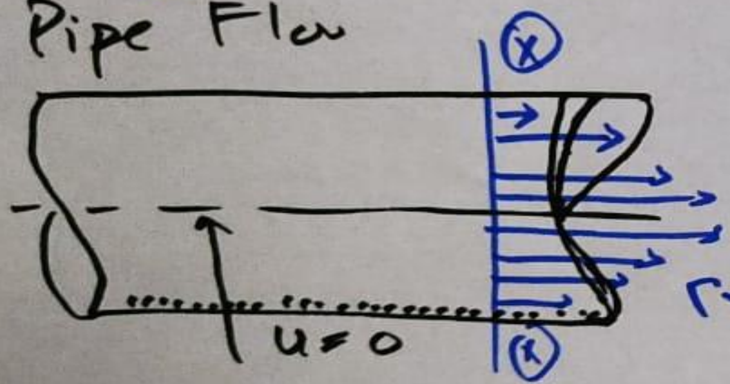
$$\Rightarrow \int d\dot{m} = \int \rho V_n dA$$

$\therefore V_n$ = Velocity normal to the plane.

$$\boxed{\dot{m} = \int \rho V_n dA}$$

Valid for Incompressible / Compressible Fluids.

e.g. Pipe Flow



At wall of Pipe velocity $u = 0$

u is maximum at center.

velocity Distribution

velocity Profile.

$$V_{Avg} = \frac{1}{A} \int V_n dA$$

$$\boxed{\dot{m} = \rho V_{avg} A}$$

$V = V_{avg}$

$$\boxed{\dot{m} = \rho A V_{avg}}$$

kg/s

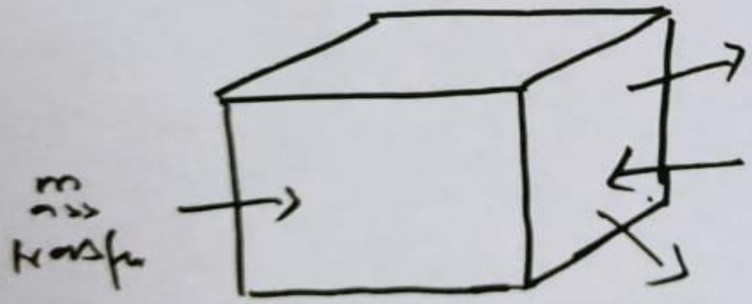
Open System : Control Volume Approach.

$\longleftrightarrow$ Also known as

Eulerian Approach in Fluid Mechanics

Closed System : Control Mass Approach

Also called as Longragian approach in Fluid Mechanics



control surfaces

Conservation of mass

"mass cannot be created or destroyed only change one form to other"

e.g. 1kg of water 1kg of steam

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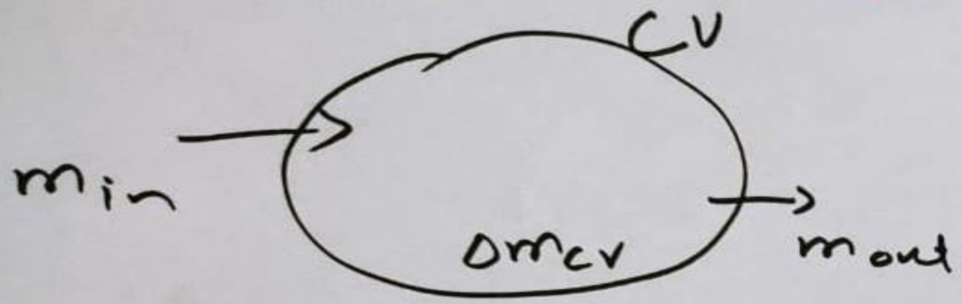
Conservation of mass (Mathematically)



$m_{in} > m_{out}$?

Δm_{cv} = mass accumulated

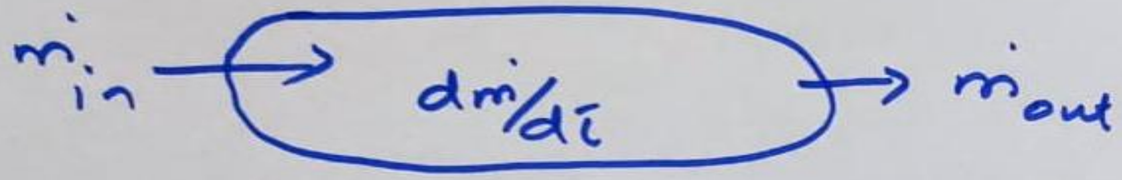
$$m_{in} - m_{out} = \Delta m_{cv}$$

Time Rate: $\boxed{\dot{m}_{in} - \dot{m}_{out} = \frac{d\dot{m}}{d\tau}}$

$d\tau$ = time interval.

$\frac{d\dot{m}}{d\tau}$ = Rate of mass accumulation

For Steady Flow



$$\frac{d\dot{m}}{d\tau} = 0$$

Rate of accumulation $= 0$

Mass:-

Mass accumulated within the system with respect to time will remain constant

$$\boxed{\dot{m}_{cv} = \text{constant}}$$

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$$\boxed{\frac{d\dot{m}}{d\tau} = 0}$$

$$\dot{m}_{in} - \dot{m}_{out} = 0$$

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

Conservation of mass For Steady Flow

$$\boxed{\rho A_1 v_1 = \rho A_2 v_2}$$ Continuity Equation

Valid for compressible as well as incompressive fluids.

Mass Balance $$\boxed{\dot{m}_{in} - \dot{m}_{out} = \frac{dm}{d\tau}}$$ Unsteady Flow

Mass Balance $$\boxed{\dot{m}_{in} = \dot{m}_{out}}$$ Steady Flow

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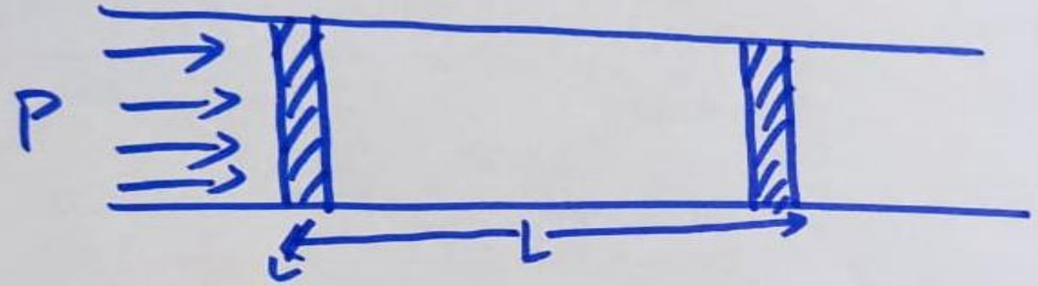
Flow Work:- Work Required to maintain the flow

Consider a passage



Area of Element $\perp$ to P

$W = F \times \text{displacement}$

$= P \times A \times l$

$$\boxed{W = PV}$$

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Total Energy:-

E = Internal Energy + Kinetic Energy + Potential Energy

$$E = U + \frac{1}{2}mv^2 + mgz$$ KJ / J

Specific Total Energy :-

$$E/m = \frac{U}{m} + \frac{1}{2}\frac{\cancel{m}v^2}{\cancel{m}} + \frac{\cancel{m}gz}{\cancel{m}}$$

$$\boxed{e = u + \frac{1}{2}v^2 + gz}$$ KJ/kg , J/kg

Energy Balance :-

PTO

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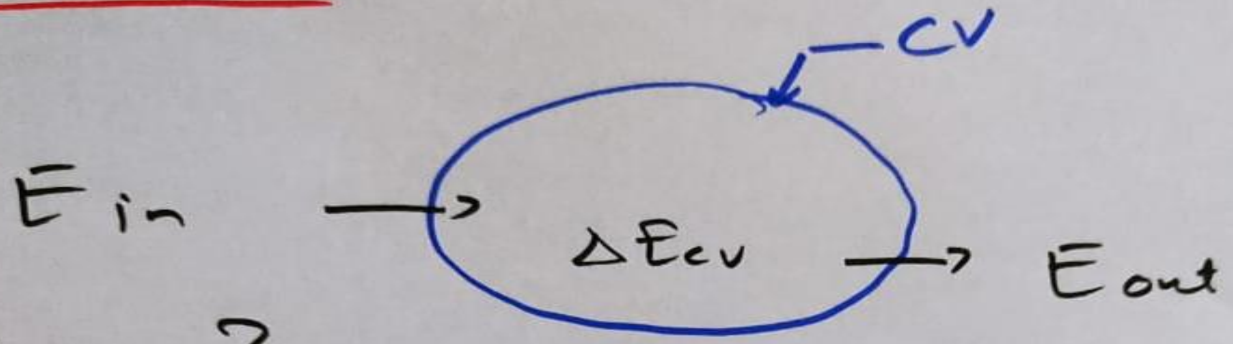
Energy Balance



$E_{in} > E_{out}$?

$$E_{in} - E_{out} = \Delta E_{cv}$$

ΔE_{cv} = Energy Accumulated inside the control volume.

Time Rate:-

$$\boxed{\dot{E}_{in} - \dot{E}_{out} = \frac{dE}{d\tau}}$$

For $\underline{\text{Steady Flow}}$

ΔE_{cv} = Constant

$$\frac{dE_{cv}}{d\tau} = 0$$

$$\boxed{\dot{E}_{in} - \dot{E}_{out} = 0}$$

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

Steady Flow

Now $\underline{\text{to derive the}}$

$\underline{\text{SFEE}}$

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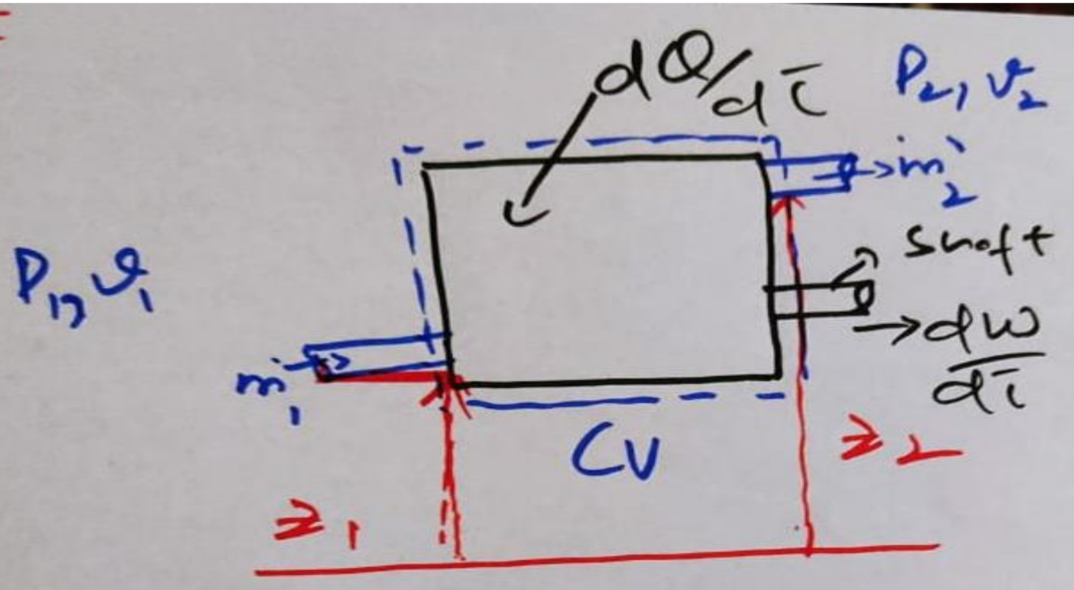
SFEE



Steady Flow Device

$$\frac{d\dot{m}}{d\tau} = 0$$

$$\frac{d\dot{E}}{d\tau} = 0$$

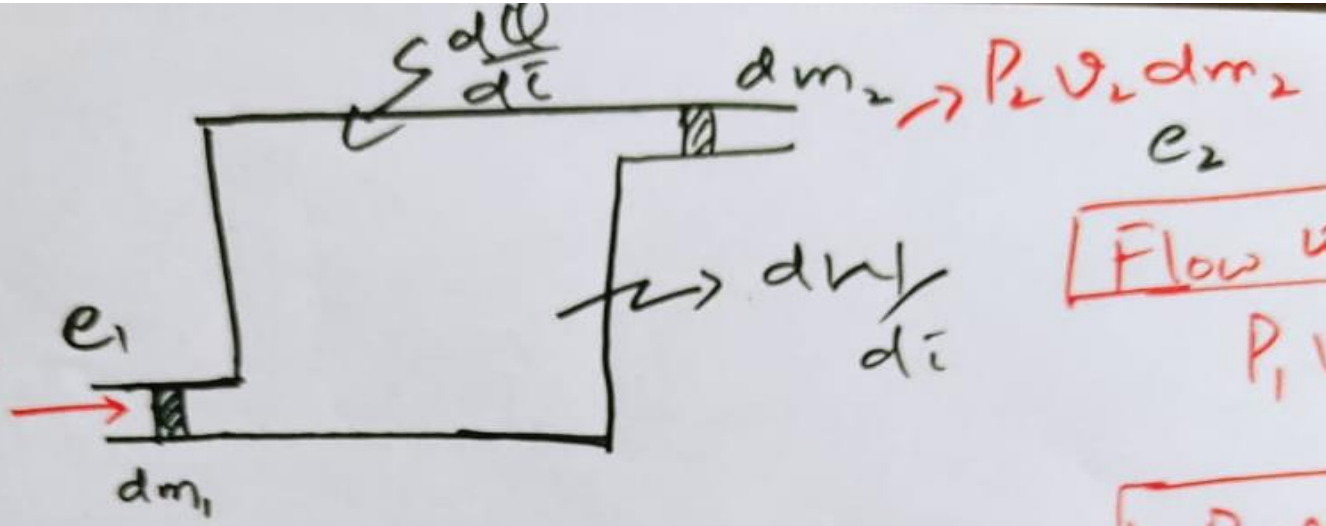
No mass & energy accumulation

In a steady flow system there are two types of work transfer

→ External Work → Shaft Work
→ Electric Work

→ Flow Work

(B)



$\boxed{\text{Flow work per unit mass } P_1 v_1}$

Total Work transfer

Flow Work $\boxed{P_1 v_1 dm_1}$

$$W = W_x - P_1 v_1 dm_1 + P_2 v_2 dm_2$$

External work — Work added into the system — Work done by the system

Time Rate
$$\frac{dW}{d\tau} = \frac{dW_x}{d\tau} - \frac{P_1 v_1 dm_1}{d\tau} + \frac{P_2 v_2 dm_2}{d\tau}$$

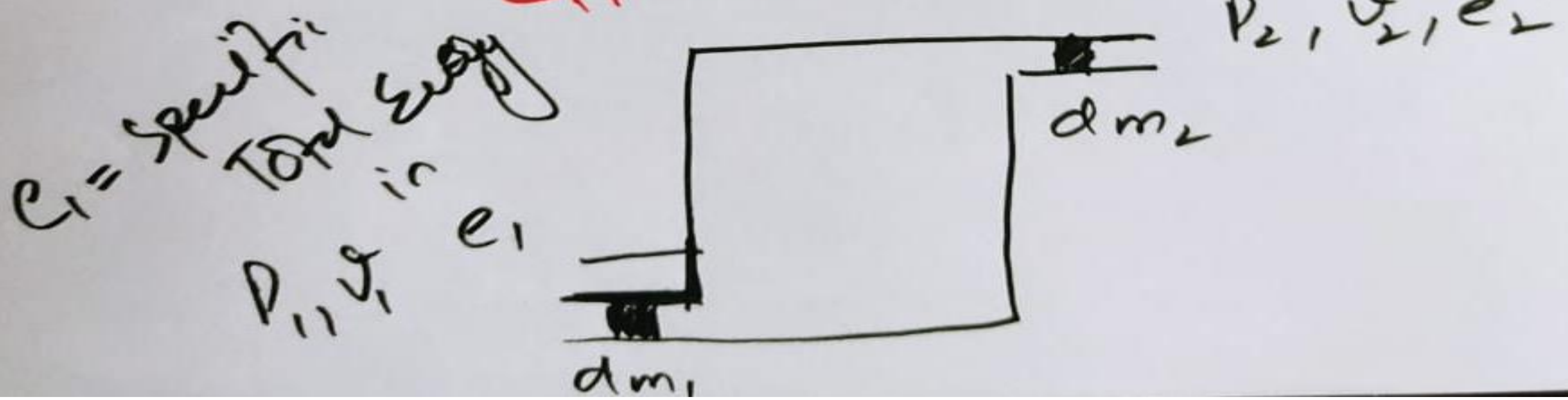
$$\frac{dm_1'}{d\tau} = \text{Inlet mass Flow Rate} = \dot{m}_1$$

$$\frac{dm_2'}{d\tau} = \text{Outlet mass Flow rate} = \dot{m}_2$$

$$\frac{dW}{d\tau} = \frac{dW_x}{d\tau} - P_1 v_1 \dot{m}_1 + P_2 v_2 \dot{m}_2$$

Rate of Work transfer (Shaft Work)

External Rate of Work transfer



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$$\dot{m}_1 e_1 + \frac{dQ}{d\tau} = \dot{m}_2 e_2 \frac{dW}{d\tau}$$

$$\boxed{e_1 = u + \frac{1}{2}v^2 + gz}$$

$$\dot{m}_1\left(u_1 + \frac{v_1^2}{2} + gz_1\right) + \frac{dQ}{\tau}$$

$$= \dot{m}_2\left(u_2 + \frac{v_2^2}{2} + gz_2\right) + \frac{dW}{d\tau}$$

$$\dot{m}_1\left(u_1 + \frac{v_1^2}{2} + gz_1\right) + \frac{dQ}{d\tau} = \dot{m}_2\left(u_2 + \frac{v_2^2}{2} + gz_2\right)$$

$$+ \frac{dW_u}{d\tau} - P_1 v_1 \dot{m}_1 + P_2 v_2 \dot{m}_2 \qquad (15$$

$$\dot{m}_1\left(u_1 + \frac{v_1^2}{2} + gz_1\right) + \frac{dQ}{d\tau} = \dot{m}_2\left(u_2 + \frac{v_2^2}{2} + gz_2\right) + \frac{dW_x}{d\tau}$$
$$- P_1 v_1 \dot{m}_1 + P_2 v_2 \dot{m}_2$$

$$\dot{m}_1\left(u_1 + \frac{v_1^2}{2} + gz_1 + P_1 v_1\right) + \frac{dQ}{d\tau} = \dot{m}_2\left(u_2 + \frac{v_2^2}{2} + gz_2 + P_2 v_2\right)$$
$$+ \frac{dW_x}{d\tau}$$

$h = u + Pv$

→ External Work per unit time.

Rate, Time:

$$\dot{m}_1\left(h_1 + \frac{v_1^2}{2} + gz_1\right) + \frac{dQ}{d\tau} = \dot{m}_2\left(h_2 + gz_2 + \frac{v_2^2}{2}\right) \frac{dW_x}{d\tau}$$

Steady Flow

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

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$$\dot{m}_1 = \dot{m}_2 = \dot{m} = \frac{dm}{d\tau} \therefore \text{ Steady Flow}$$

SFEE on time basis

$$\frac{dm}{d\tau}\left(h_1 + \frac{V_1^2}{2} + g z_1\right) + \frac{dQ}{d\tau} = \frac{dm}{d\tau}\left(h_2 + \frac{V_1^2}{2} + g z_2\right) + \frac{dW_x}{d\tau}$$

Dividing by $dm/d\tau$ both sides

$$h_1 + \frac{V_1^2}{2} + g z_1 + \frac{dQ}{dm} = h_2 + \frac{V_1^2}{2} + g z_2 + \frac{dW_x}{dm}$$

SFEE on mass basis

$\frac{dQ}{dm}$ KJ/Kg, J/Kg

$\frac{dW}{dm}$ KJ/Kg, J/Kg

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Bernoulli Equation is a special case of SFEE.

Bernoulli Equation	SFEE
Valid for only Incompressible Fluids	Valid for both incompressible & compressible Fluids.

SFEE → First law of thermodynamics for open system.