First law in Flow processes –

Energy is state properties but not work

Specific ~~work~~ heat capacity

$h = u + pv$

$\Delta E = Q + W$

$E = E_K + E_p + U$

$Q = \Delta E_K + \Delta E_p + \Delta U - W$

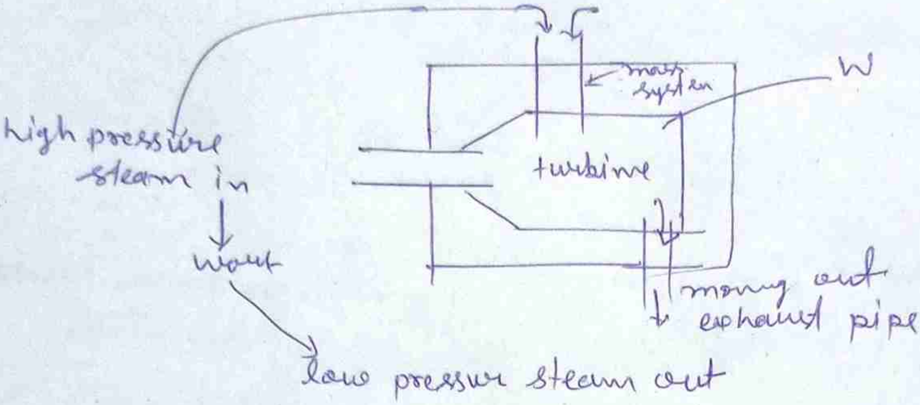
flow work

$dW_{flow} = p v \, dm$

where $dV = v \, dm$

①

mass transfer from boundary → open system



to analyze expansion –

moving part should be followed taking account heat & work → lagrangian

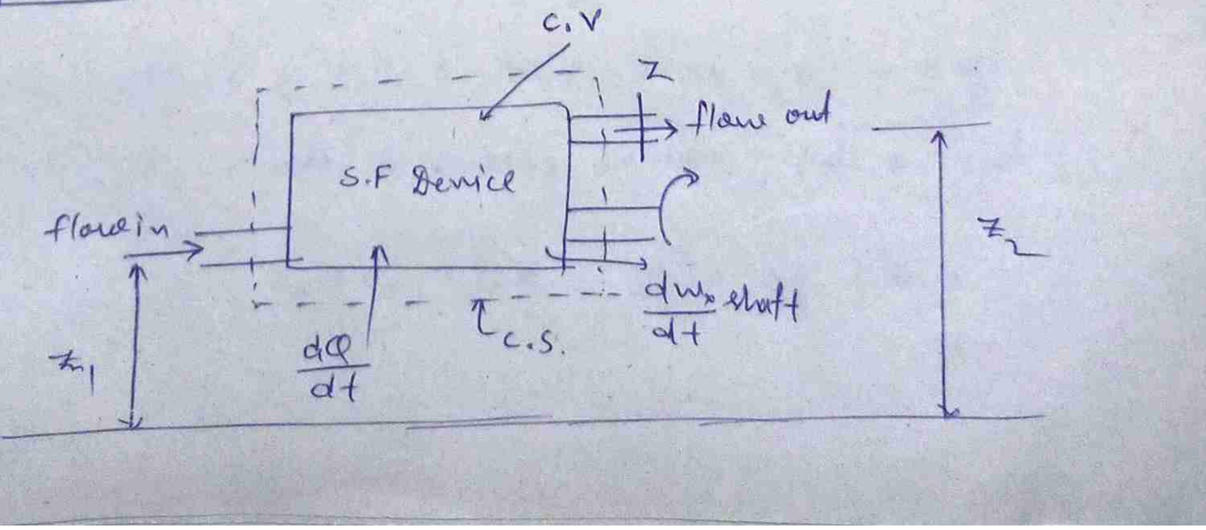
Alternatively : → in the Control volume what happen ?

System : → boundary can change !

but control volume → remain same

} Eulerian

Steady flow : . mass & energy balance in simple S.S flow



②

$w_1 = w_2$ — Area

$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$ → velocity in

<u>Energy balance :-</u>

work transfer for flow

external work

flow work

↓

shear (shaft or stirring)

electrical

at inlet, outlet

$(+ P_1 v_1 dm_1, - P_2, v_2, dm_2)$

total work transfer -

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

<u>in the rate form</u>

$$\frac{dW}{dt} = - \frac{dW_x}{dt} + P_1 v_1 \frac{dm_1}{dt} - P_2 v_2 \frac{dm_2}{dt}$$

$$\frac{dW}{dt} = - \frac{dW_x}{dt} + w_1 P_1 v_1 - P_2 v_2 w_2$$

by conservation of energy at S.S.

energy in = energy out.

$$\frac{dW}{dt} + w_1 e_1 + \frac{dQ}{dt} = w_2 e_2$$

$$w_1 e_1 + \frac{dQ}{dt} + w_1 P_1 v_1 = w_2 e_2 + w_2 P_2 v_2 + \frac{dW_x}{dt}$$

$e_1, e_2 \rightarrow$ refer to energy carried into or out

$$e = e_K + e_P + u = \frac{V^2}{2} + Zg + u$$

(3)

$$e = e_k + e_p + u = \frac{V^2}{2} + Zg + u$$

$$w_1\left(\frac{V_1^2}{2} + Z_1 g + u_1\right) + w_1 P_1 v_1 + \frac{dQ}{dt}$$

$$= w_2\left(\frac{V_2^2}{2} + Z_2 g + u_2\right) + w_2 P_2 v_2 + \frac{dW_x}{dt}$$

$$= w_1\left(\frac{V_1^2}{2} + Z_1 g + h_1\right) + \frac{dQ}{dt}$$

$$= w_2\left(\frac{V_2^2}{2} + Z_2 g + h_2\right) + \frac{dW_x}{dt} \quad \text{—— (A)}$$

$$h = u + pv$$

Since,

$$w_1 = w_2 = w = \frac{dm}{dt}$$

First substituting w, then $\div \frac{dm}{dt}$

$$\Rightarrow h_1 + \frac{V_1^2}{2} + Z_1 g + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + Z_2 g + \frac{dW_x}{dm} \quad \text{—— (B)}$$

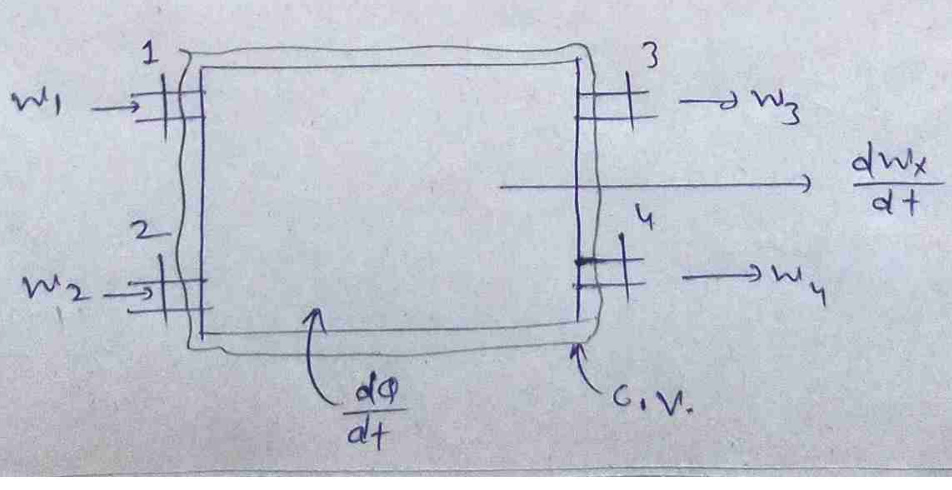
Steady flow energy equation (SFEE)

Eq^n (A) & (B) represent energy flow per unit time & per ~~unit~~ unit masses, respectively.

Eq^n (B) is more convenient

Eq^n (B) can be written in more convenient form.

More than one steam –



mass balance,

$$w_1 + w_2 = w_3 + w_4$$

or,
$$\frac{A_1 V_1}{v_1} + \frac{A_2 V_2}{v_2} = \frac{A_3 V_3}{v_3} + \frac{A_4 V_4}{v_4}$$

Energy balance

$$w_1 \left(h_1 + \frac{v_1^2}{2} + z_1 g \right) + w_2 \left(h_2 + \frac{v_2^2}{2} + z_2 g \right) + \frac{dQ}{dt}$$
$$= w_3 \left(h_3 + \frac{v_3^2}{2} + z_3 g \right) + w_4 \left(h_4 + \frac{v_4^2}{2} + z_4 g \right) + \frac{dw_x}{dt}$$

~~Stat~~ Steady state energy eqn —
Applied to —

→ pipe line flows
→ heat tranfer process
→ mechanical power generation in engines.
→ turbines, combustion process
→ flow through nozzles & diff~~users~~. → diffusers

Some terms in some cases may be negligible or zero.
but start with full eqn and drop terms.

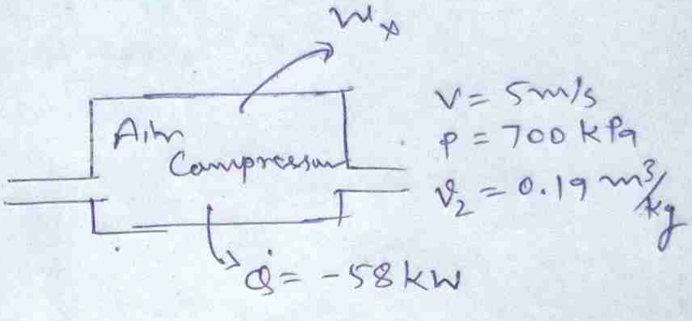
Air flow at 0.5 kg/s (at s.s.) through a compressor at 7 m/s ($V = 7$ m/s) ⑤

inlet $\quad p = 100$ kPa

$\quad v = 0.95\ m^3/kg$.

$$w_1 = \frac{A_1 V_1}{v_1}$$

$$= \frac{A_2 V_2}{v_2} = 0.5\ kg/s$$



$$u_2 - u_1 = 90\ kJ/kg$$

$$w_1\left(h_1 + \frac{V_1^2}{2} + z_1 g\right) + \frac{dQ}{dt} = w_2\left(h_2 + \frac{V_2^2}{2} + z_2 g\right) + \frac{dw_x}{dt}$$

$$\frac{dw_x}{dt} = w\left((u_1 - u_2) + p_1 v_1 - p_2 v_2 + \frac{V_1^2 - V_2^2}{2}\right) + \dot{Q}$$

$$= 0.5\ kg/s\ \Big[-90\ kJ/kg + 10^5\ kg\,m^{-1}s^{-2} \times 0.95\ m^3/kg - 1\times10^5\ kg\,m^{-1}s^{-2} \times 0.19\ m^3/kg$$

$$+ \left(\frac{7^2 - 5^2}{2}\right) m^2 s^{-2}\Big] - 58\ kJ/s$$

$$= 0.5\,[-90 + 95 - 133 + 12) - 58$$

$$\simeq -64 - 58$$

$$= -122\ kW$$

ⓑ $\left(\frac{A_1}{A_2}\right)^{1/2}$

$$\Rightarrow \quad w = \frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

$$\Rightarrow \quad \frac{A_1}{A_2} = \frac{V_2 v_1}{V_1 v_2} = \frac{5\ m/s \times 0.95\ m^3/kg}{7\ m/s \times 0.19\ m^3/kg}$$

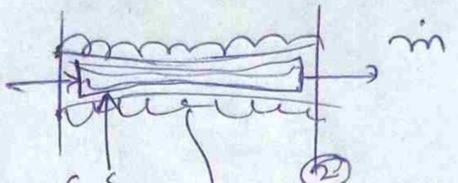
$$= \frac{4.75}{1.33} = 3.57$$

$$\boxed{\frac{d_1}{d_2} = 1.89}$$

Some Engineering application of energy eqⁿ. (6)

Nozzle & diffuser → increase pressure & K.E.

↓ increases velocity or K.E. of a fluid at expanse of pressure drop.



at S.S energy balance —

$$\frac{dm}{dt}\left(h_1 + \frac{V_1^2}{2} + Z_1 g\right) + \frac{dQ}{dt} = \frac{dm}{dt}\left(h_2 + \frac{V_2^2}{2} + Z_2 g\right) + \frac{dW_x}{dt}$$

$$Z_2 - Z_1 = 0$$

$$\Rightarrow \quad h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$w = \frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

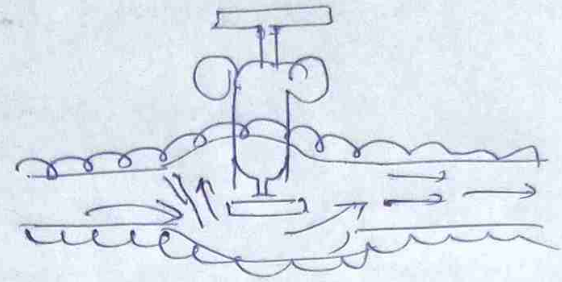
if $V_1 << V_2$

$$\Rightarrow \quad h_1 = h_2 + \frac{V_2^2}{2}$$

$$\Rightarrow \quad V_2 = \sqrt{2(h_1 - h_2)} \quad m/s$$

$$(h_1 - h_2) \sim J/kg$$

Throttling Device :-



flow through a constricted passage

an appreciable drop in pressure.

$$\frac{dQ}{dm} = 0, \quad \frac{dW_x}{dm} = 0$$

$$\Rightarrow \quad h_1 + \frac{v_1^2}{2} = h_2 \frac{v_2^2}{2}$$

no change in K.E.

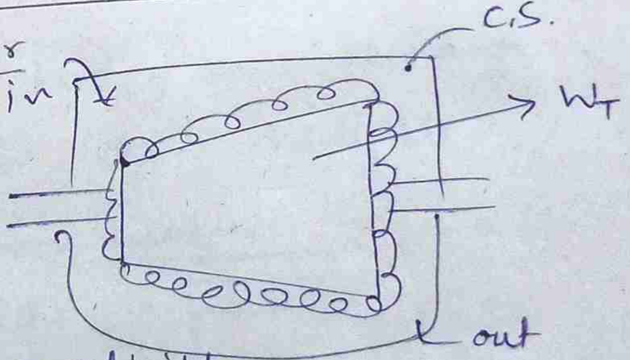
$$\Rightarrow \quad h_1 = h_2$$

pressure energy converted to internal energy

$$h = u + pv \quad \text{specific value}$$

$$u_1 + P_1 v_1 = u_2 + P_2 v_2$$

Turbine & Compressor



turbine -
well insulated
& flow velocity low.

if ΔK.E. is negligible

$$h_1 = h_2 + \frac{dW_x}{dm} \quad \Rightarrow \quad \frac{W_x}{m} = (h_1 - h_2)$$

Similarly for pump & Comp. -

$$\frac{W_x}{m} = (h_1 - h_2) < 0$$

$\Rightarrow$ Shaft work on the system.

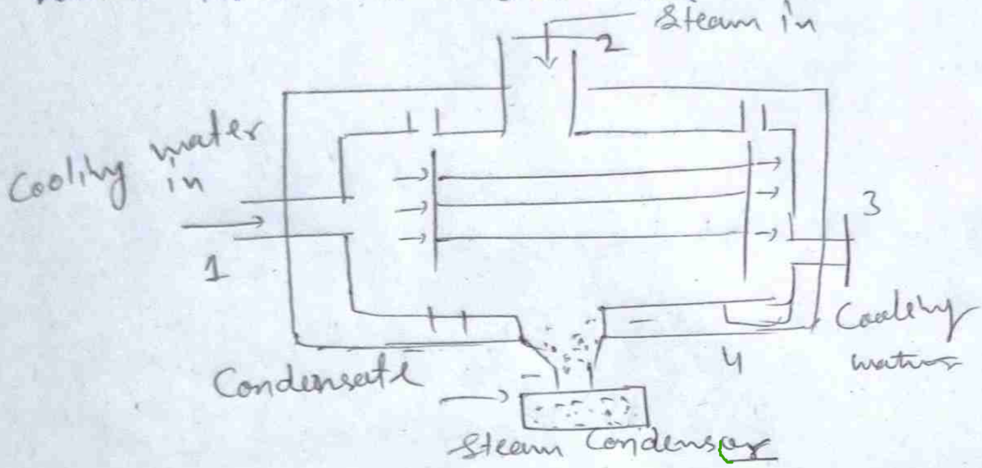
Heat exchanger

↳ heat transfer from one fluid to another

→ steam condenser

↓

steam condenser outside the tube & cooling water flow inside the tube



The steady flow energy eqn for C.S.

$$w_c h_1 + w_s h_2 = w_c h_3 + w_4 h_4$$

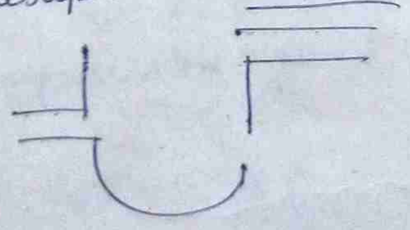
or

$$w_s (h_2 - h_4) = w_c (h_3 - h_1)$$

here no external heat & work exchange

k.E. & P.E. terms negligible

Steam desuper heating



Comparision of S.F.E.E. with Euler & Bernoulli Eqn

S.F.E.E

$$\frac{dQ}{dm} = (h_2 - h_1) + \frac{\bar{V}_2^2 - \bar{V}_1^2}{2} + (Z_2 - Z_1)g + \frac{dW_s}{dm}$$

$$\Rightarrow \quad dq = dh + \underline{v}\, d\underline{v} + g\,dz + dw_x$$

$$h = u + pv \Rightarrow \underbrace{dq = du + p\,dv}_{\text{for quasi-static work only involve pdv work.}}$$

So

$$du + p\,dv = du + p\,dv + v\,dp + V\,dV + g\,dz + dw_x$$

$$\Rightarrow \quad v\,dp + V\,dV + g\,dz = 0$$

for incompressible fluid

$v \rightarrow$ Constant

$$\Rightarrow \quad v(P_2 - P_1) + \frac{V_2^2}{2} - \frac{V_1^2}{2} + g(Z_2 - Z_1) = 0$$

$$\Rightarrow \quad \frac{P_1}{\rho} + \frac{V_1^2}{2} + Z_1 g = \frac{P_2}{\rho} + \frac{V_2^2}{2} + Z_2 g$$

$$\Rightarrow \quad \frac{P}{\rho} + \frac{V^2}{2} + Z g = \text{Constant}$$

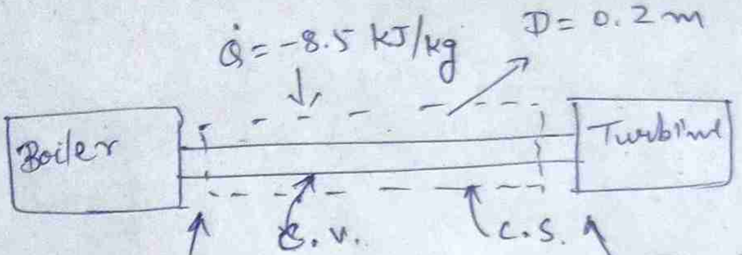
$$\Rightarrow \quad \Delta\left(pv + \frac{V^2}{2} + gz\right) = 0$$

this is Bernoulli eqn.

which is valid inviscid incompressible fluid.

<u>S.F.E.E.</u> $Q - W_x = \Delta\left(u + pv + \frac{V^2}{2} + g\right)$

Ex. steam power station



Steam Condition

P = 4 MPa

T = 400°C

$h = 3213.6$ kJ/kg

$v = 0.073$ m³/kg

P = 3.5 MPa

T = 392°C

$h = 3202.6$ kJ/kg

$v = 0.084$ m³/kg

Calculate V & Q.

$$h_1 + \frac{V_1^2}{2} + Z_1 g + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + Z_2 g + \frac{dW_x}{dm}$$

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} \Rightarrow V_2 = \frac{v_2}{v_1} V_1 = 1.15 V_1$$

and $\frac{dW_x}{dm} = 0$

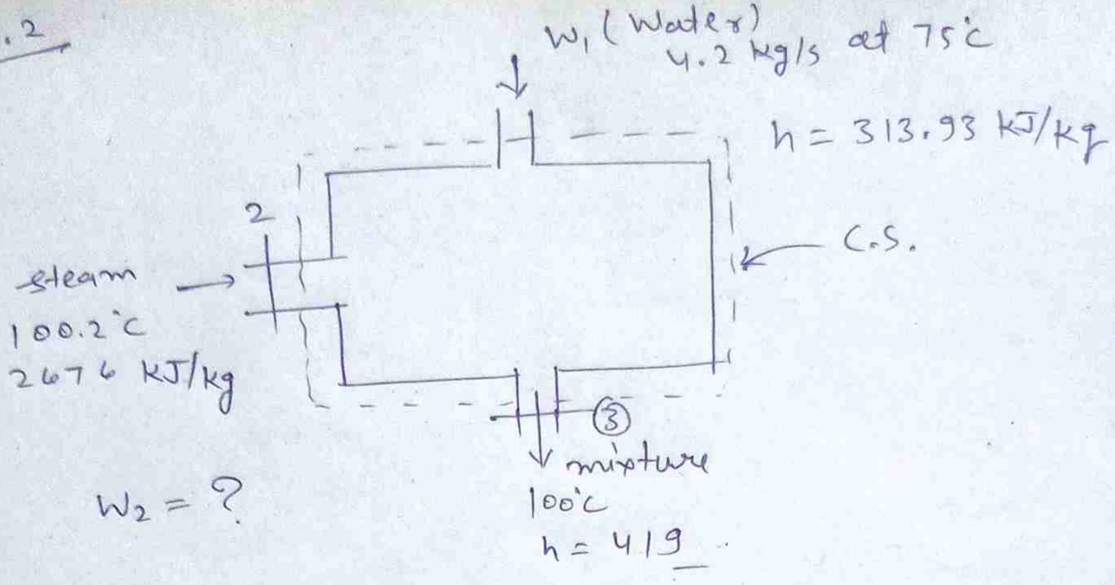
$Z_1 \approx Z_2$

$$h_1 + \frac{V_1^2}{2} + \frac{dQ}{dm} = h_2 + \frac{(1.15V_1)^2}{2}$$

$\Rightarrow \quad V_1 = 125.1$ m/s

$\Rightarrow \quad w = 53.8$ kg/s.

Ex. 2



$W_2 = ?$

mass balance

$$w_1 + w_2 = w_3 \quad \text{——— (1)}$$

energy balance

$$w_1\left(h_1 + \frac{v_1^2}{2} + z_1 g\right) + \frac{dQ}{dt}$$

$$+ w_2\left(h_2 + \frac{v_2^2}{2} + z_2 g\right)$$

$$= w_3\left(h_3 + v_3^2/2 + z_3 g\right) + \cancel{\frac{dW_x}{dt}}^{\,0}$$

No - shaft work.
P.E. & K.E. negligible.

$$\Rightarrow \quad w_1 h_1 + w_2 h_2 = w_3 h_3 \quad \text{——— (2)}$$

from (1) & (2)

$$\Rightarrow \quad w_2 = 705 \text{ kg/h}$$