First Law Applied to Flow Processes

For any system and in any process, the first law can be written as

$$Q = \Delta E + W \quad \text{---(1)}$$

where E represents all forms of energy stored in the system.

For a pure substance $E = E_K + E_P + U$ — (2)

where E_K is the kinetic energy, E_P is the potential energy and U is the residual energy stored in the molecular structure of the substance.

From (1) & (2) $Q = \Delta E_K + \Delta E_P + \Delta U + W$

First Law Applied to Steady Flow Process

A flow process is said to be steady when the fluid parameters or thermodynamic property at any point of the control volume (CV) remains constant with respect to time or will not alter with time. The thermodynamic properties may vary along space co-ordinates i.e may, however be different at different cross-section of the flow passage.

i.e $\frac{d(\text{Thermodynamic property})}{dt} = 0$ ∵ Thermodynamic property is constant.

Continuity equation or Conservation of mass states that " the mass of the system can neither be created nor destroyed but its amount remains constant during any process" It only changes its form (phases)".

Total mass entering CV − Total mass leaving CV = Net change in mass within the C.V

The volume flow rate through a cross-sectional area per unit time is called fluid discharge rate (G)

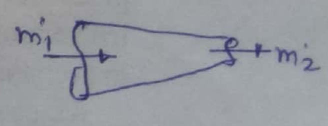
$G = AC$ where A is cross sectional area of flow in m^2
$G = AC \ m^3/sec$ C is fluid velocity in m/s

The amount of mass flowing through a cross-sectional per unit time is called the mass flow rate ($\dot{m}$)

$\dot{m} = \rho AC \quad \left(Kg/m^3 \times \frac{m^3}{sec} = Kg/sec\right)$

ρ = Density in Kg/m^3, $v = \frac{1}{\rho}$ = specific volume m^3/kg

For steady flow, no accumulation of mass inside the control volume



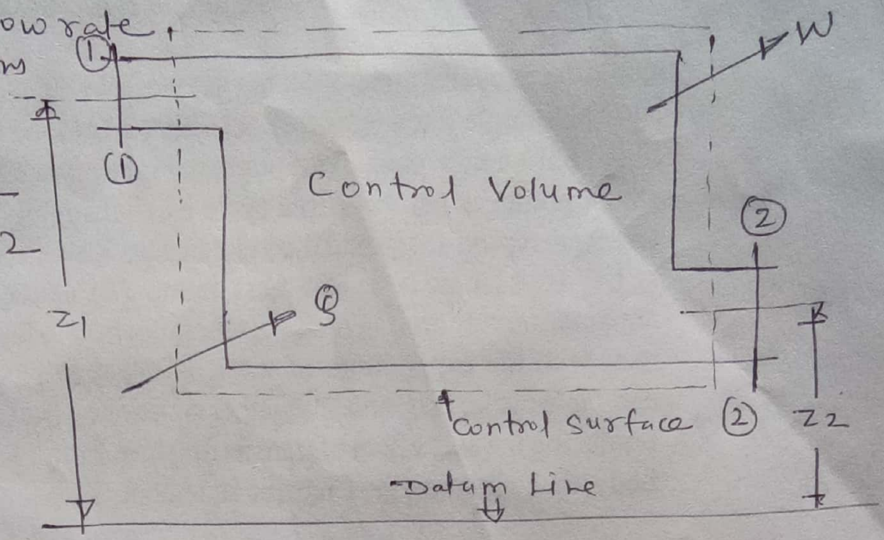
∴ $\dot{m}_1 = \dot{m}_2 \Rightarrow \rho_1 A_1 C_1 = \rho_2 A_2 C_2$

∵ Same medium $\rho_1 = \rho_2 \Rightarrow A_1 C_1 = A_2 C_2 \Rightarrow G_1 = G_2$

Steady Flow Energy Equation (SFEE)

Assumed the mass flow rate through the system remains constant

In figure entry at Section 1-1 and exit occurs at Section 2-2



In a steady flow system, there is no accumulation of mass or energy with in the control volume and properties at any location within the control volume are steady with time. Section 1-1 and Section 2-2 indicate, respectively, the entrance and exit of the fluid across the control volume. The fluid enters the control volume with velocity c_1, pressure P_1, specific volume v_1 and specific internal energy u_1

The corresponding values at the exit section 2-2 are c_2, P_2, v_2 and u_2

Further during, the fluid flow between two sections, heat (Q) and work (W) may also cross the control volume

According to 1st Law of Thermodynamics

Total energy enters in to C.V = Total energy outlet from the C.V.

Total energy of the fluid at Section 1-1 + Heat supplied = Total energy at Section 2-2 + work

$$m_1\left[u_1 + P_1V_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m_2\left[u_2 + P_2V_2 + \frac{c_2^2}{2} + gz_2\right] + W$$

For steady flow $m_1 = m_2 = m$

$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W \quad \left[\because h = u + Pv\right]$$

For unit mass $\left(h_1 + \frac{c_1^2}{2} + gz_1\right) + q = \left(h_2 + \frac{c_2^2}{2} + gz_2\right) + w$

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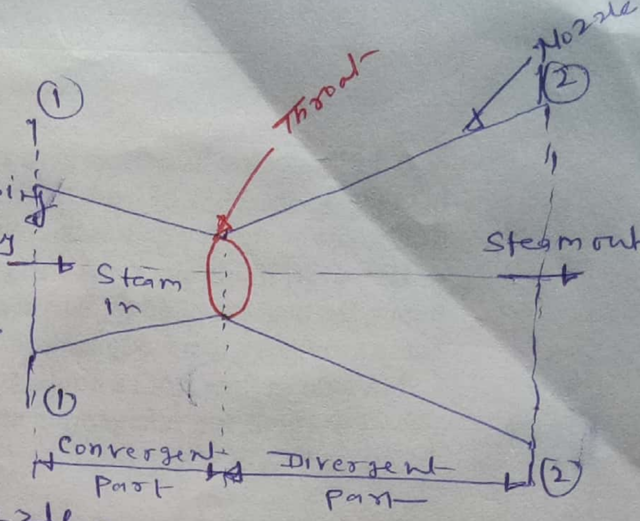
Application of SFEE

(1) Nozzles and Diffusers



A nozzle is a device for increasing the velocity of fluid of a steadily flowing ~~steam~~ steam at the expense of its pressure, hence enthalpy.

A Diffuser is a device that increases the pressure of the by slowing it down. Hence nozzle and Diffuser perform opposite task.

Applying SFEE at entry and exit

$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W \quad \text{—(A)}$$

In nozzle $W = 0$, $Q = 0$ (Thermally Insulated),

$Z_1 = Z_2$ (nozzle is horizontal)

In equation (A) $Q = 0$, $W = 0$, $gz_1 = gz_2$

$$m\left[h_1 + \frac{c_1^2}{2}\right] = m\left[h_2 + \frac{c_2^2}{2}\right]$$

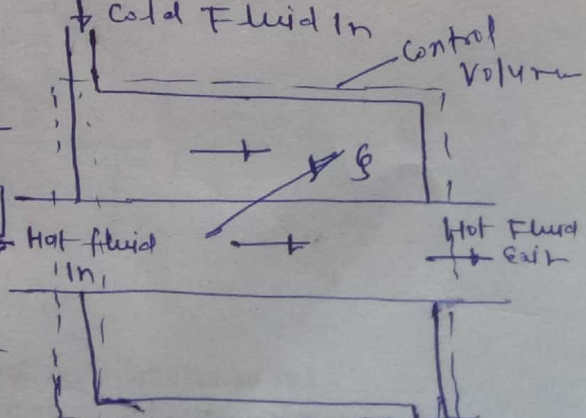
$$\frac{c_2^2}{2} - \frac{c_1^2}{2} = h_1 - h_2$$

$$c_2^2 - c_1^2 = 2(h_1 - h_2) \quad \therefore \quad c_2^2 = c_1^2 + 2(h_1 - h_2)$$

$$c_2 = \sqrt{c_1^2 + 2(h_2 - h_1)}$$

$$c_2 = \sqrt{2(h_1 - h_2)} \quad \text{if } c_2 \ggg c_1$$

(2) Heat Exchanger



SFEE for Hot fluid inlet and exit

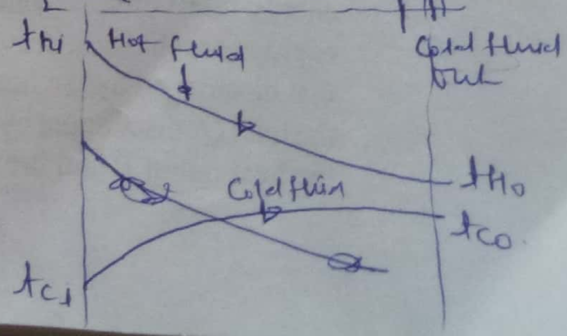
$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W$$

In Heat exchanger $W = 0$

Velocity at inlet is approximately the same at outlet $c_1 \simeq c_2 \Rightarrow c_1 = c_2$

Heat exchange is horizontal $Z_1 = Z_2$

$$\therefore mh_1 + Q = mh_2 \Rightarrow Q = m(h_2 - h_1)$$



(c) Boiler → A boiler is also a type of heat exchanger

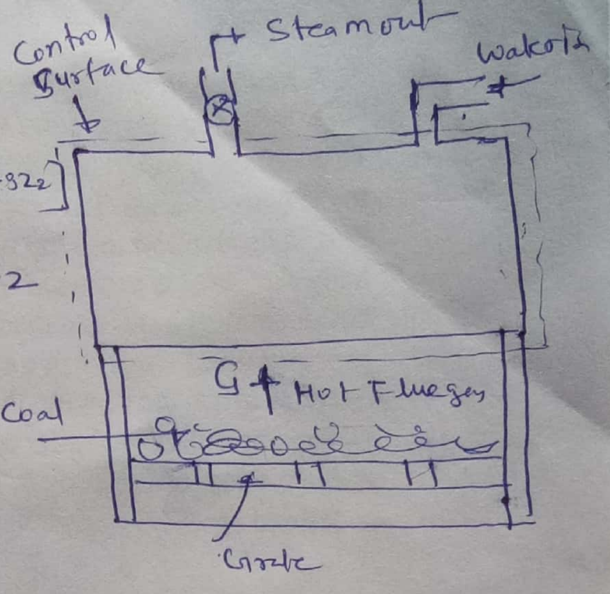
SFEE at water inlet and Steam exit

$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W$$

In boiler, $W = 0$, $c_1 \simeq c_2$, $z_1 = z_2$

$\Rightarrow m h_1 + Q = m h_2$

$Q = m h_2 - m h_1 = m(h_2 - h_1)$

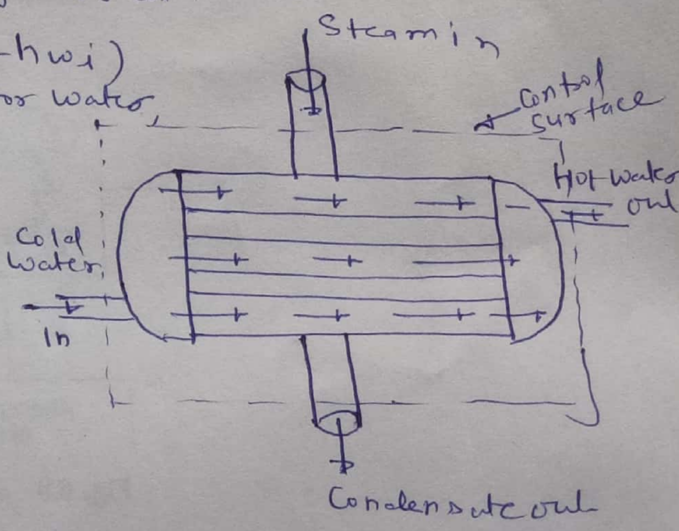


(d) Condenser

Heat lost by Steam = Heat gain by cold water

$m_s(h_{si} - h_{so}) = m_w(h_{wo} - h_{wi})$

s suffix is for Steam, w is for water, i → inlet, o → outlet



(e) Turbine –

SFEE is

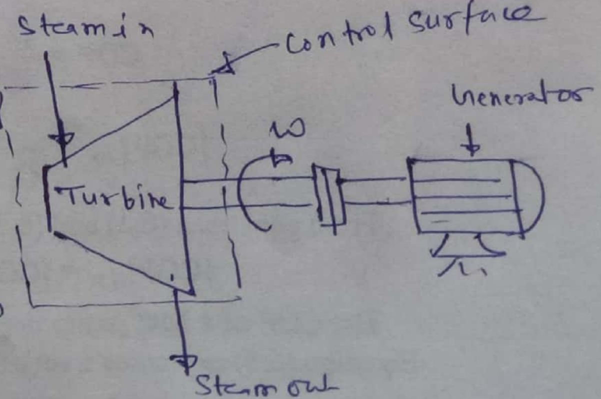
$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W$$

W is Shaft work

$c_1 \simeq c_2$, $z_1 = z_2$

No heat transfer from turbine as it is Insulated, $Q = 0$

$m h_1 + 0 = m h_2 + W \Rightarrow W = m(h_1 - h_2)$

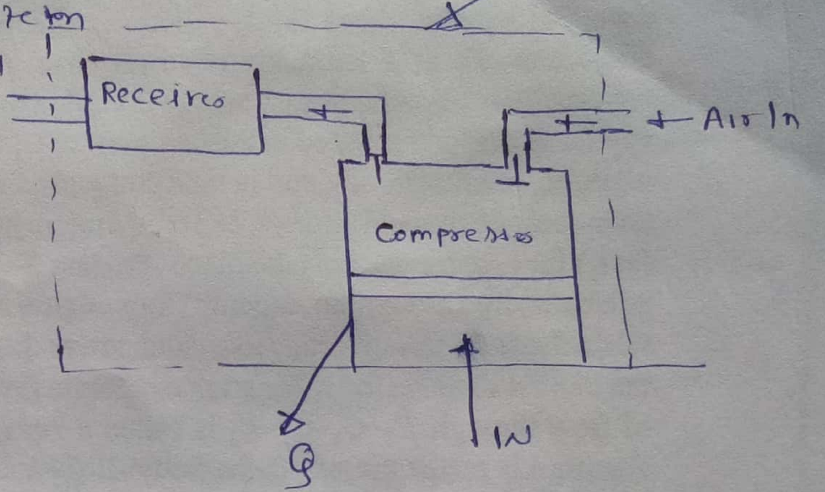


(f) Compressor →

A compressor is used to increase the pressure of a fluid

$$m\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + W$$

Work is done on the system so in above equation W will be negative



$c_1 \simeq c_2$, $z_1 = z_2$

Heat is rejected from the system so Q will be −ve

$$mh_1 - Q = mh_2 - W$$

$$W = Q + m(h_2 - h_1)$$