First law of Thermodynamics Applied to Steady flow process

Steady flow Process

As a fluid flows into a certain control volume, its thermodynamic ppr may vary along the space co-ordinates as well as time.

"Steady flow" means that rate of flow of mass & energy across the control surface are constant.

continuity equation:

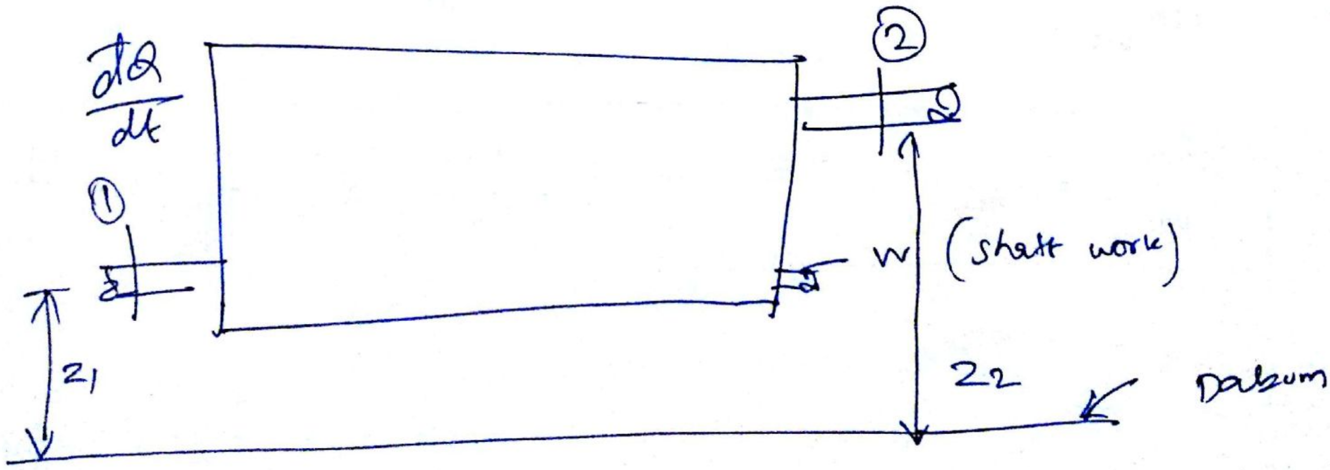
According to the continuity ~~rate~~ eqn. The inlet mass flow rate is equal to outlet mass flow rate Assuming that there is no Accumulation of mass (or) leakage insides the system.

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

energy equation:

Rate of energy in flow rate of energy out flow

$$\sum \dot{E}_{inlet} = \sum \dot{E}_{outlet}$$



$$\begin{pmatrix}\text{Amt of} \\ \text{Heat} \\ \text{transfer}\end{pmatrix}_{\text{Inlet}} + \begin{pmatrix}K.E + P.E + I.E + F.E \\ P_1 v_1\end{pmatrix}_{\text{inlet}} = \begin{pmatrix}\text{work} \\ \text{transfer}\end{pmatrix}_{\text{outlet}} + \begin{pmatrix}K.E + P.E + I.E \\ + \text{Flow} \\ \text{energy}\end{pmatrix}_{\text{outlet}}$$

$$\frac{dQ}{dt} + \dot{m}\left[\frac{1}{2}v_1^2 + gz_1 + u_1 + P_1 v_1\right] = \frac{dw}{dt} + \dot{m}\left[\frac{1}{2}v_2^2 + gz_2 + u_2 + P_2 v_2\right]$$

$$\boxed{h = u + Pv}$$

$$\frac{dQ}{dt} + \frac{dm}{dt}\left(\frac{1}{2}v_1^2 + gz_1 + h_1\right] = \frac{dw}{dt} + \frac{d\dot{m}}{dt}\left[\frac{1}{2}v_2^2 + gz_2 + \cancel{u_2 +} \cancel{P_2 v_2} h_2\right]$$

Enthalpy: enthalpy is defined as the amt of heat content inside the control volume is called enthalpy it is denoted by 'h'

$$h = u + Pv = \text{internal energy} + \text{flow energy}$$

$\div$ by $\frac{dm}{dt}$

$$\frac{dQ/\cancel{dt}}{dm/\cancel{dt}} + \frac{1}{2}v_1^2 + gz_1 + h_1 = \frac{dw}{dm} + \frac{1}{2}v_2^2 + gz_2 + h_2$$

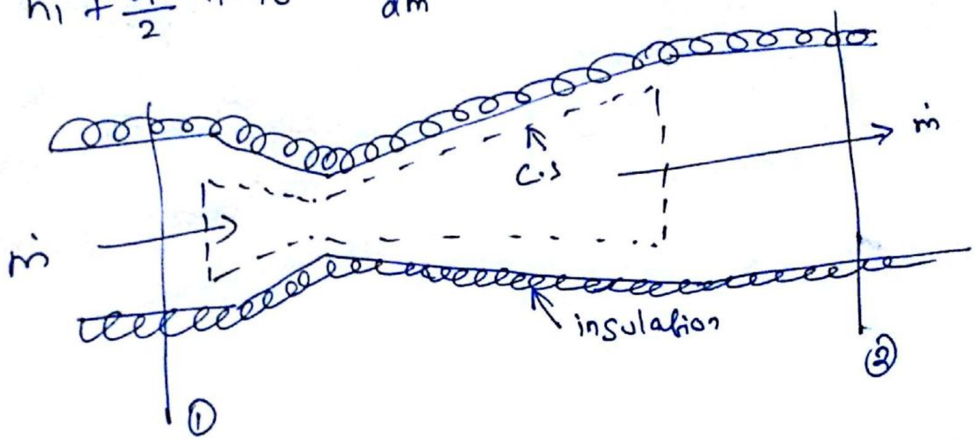
$$\boxed{\frac{dQ}{dm} + \frac{1}{2}v_1^2 + gz_1 + h_1 = \frac{dw}{dm} + \frac{1}{2}v_2^2 + gz_2 + h_2}$$

Applications

Nozzle & Diffuser

A nozzle is a device which increases the velocity (or) K.E of a fluid at the expense of its pressure drop, whereas a diffuser increases the pressure of a fluid at the expense of its K.E. nozzle which is insulated. The steady flow energy equation of the control surface gives

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



$$\frac{dQ}{dm} = 0 \qquad \frac{dW_x}{dm} = 0 \qquad Z_1 = Z_2$$

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

$$w = \frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} \quad \text{continuity eqn}$$

Inlet velocity is very very small compared to the exit velocity V_2. The above eqn becomes

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

$$V_2 = \sqrt{2(h_1 - h_2)} \ m/sec$$

$(h - h_2)$ is in J/kg

Throttling Device:

when a fluid flows through a constricted passage, like a partially opened valve there is an appreciable drop in pressure and a flow is said to be throttled. insulated pipe

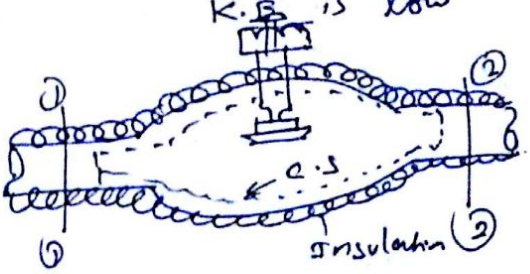
$$\frac{dQ}{dm} = 0 \qquad \frac{dW_x}{dm} = 0$$

~~K.E~~ & P.E is very small and ignored, Thus the SFEE reduces to

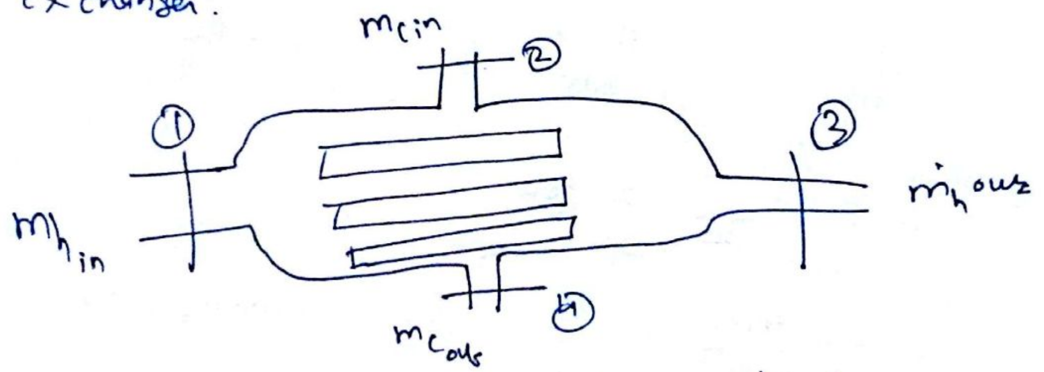
$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

K.E is low

$$\boxed{h_1 = h_2}$$



Heat exchanger:



$\dot{m}_h$ = mass flow rate of hot fluid

$\dot{m}_c$ = mass flow rate of cold fluid.

Heat exchanger is a device which exchange the heat b/w two fluids

$z_1 = z_3$
$z_2 = z_4 = 0$

$$\frac{dQ}{dt} + \dot{m}_h\left[\frac{1}{2}V_1^2 + z_1 g + h_1\right] + \dot{m}_c\left[\frac{1}{2}V_2^2 + z_2 g + h_2\right] = \frac{dW}{dt} + \dot{m}_h\left[\frac{1}{2}V_3^2 + z_3 g + h_3\right] + \dot{m}_c\left[\frac{1}{2}V_4^2 + z_4 g + h_4\right]$$

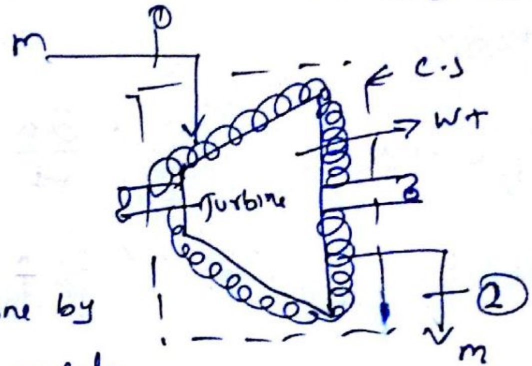
$$\frac{d\cancel{Q}}{dt}^{0} + \dot{m}_h(h_1) + \dot{m}_c(h_2) = \frac{d\cancel{W}}{dt}^{0} + \dot{m}_c(h_4) + \dot{m}_h(h_3)$$

$$\dot{m}_h[h_1 - h_3] = \dot{m}_c[h_4 - h_2]$$

Heat lost by the hot fluid = Heat gained by cold fluid

Turbine & compressor:

Turbine & engine give (+ve) work o/p. whereas compressor & pumps require power input. For turbine which is insulated the flow velocities are often small and the K.E terms can be ~~gag~~ neglected



$$h_1 = h_2 + \frac{dW_x}{dx}$$

$$\boxed{\frac{W_x}{m} = h_1 - h_2}$$

It is seen that work is done by the fluid at the expense of its enthalpy

for adiabatic pump (or) compressor, work is done upon the fluid and w is negative. So the S.F.E.E becomes

$$h_1 = h_2 - \frac{W_x}{m}$$

$$\boxed{\frac{W_x}{m} = h_2 - h_1}$$

The enthalpy of the fluid increases by the amt of work input.

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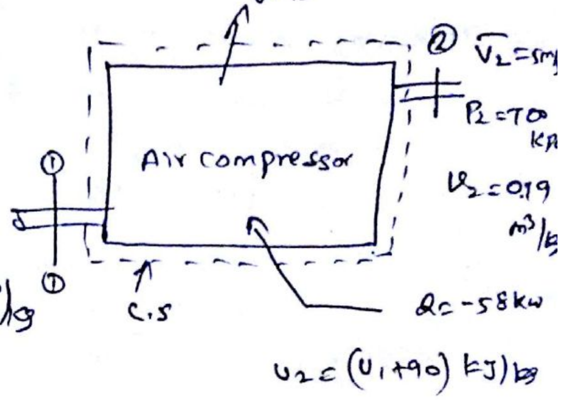
① Air flows steadily at the rate of 0.5 kg/sec through an air compressor, entering at 7 m/s velocity, 100 kPa pressure and 0.95 m^3/kg volume and leaving at 5 m/s, 700 kPa, and 0.19 m^3/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in the compressor jackets absorbs heat from the air at the rate of 58 kW.

(a) compute the rate of shaft work input to the air in kW

(b) Find the ratio of the inlet pipe diameter to outlet pipe diameter.

S.F.E.E



$$\dot{m}\left(u_1 + P_1 v_1 + \frac{V_1^2}{2} + Z_1 g\right) + \frac{dQ}{dt} = \dot{m}\left(u_2 + P_2 v_2 + \frac{V_2^2}{2} + Z_2 g\right) + \frac{dw_x}{dt}$$

$$\frac{dw_x}{dt} = -\dot{m}\left[(u_2 - u_1) + (P_2 v_2 - P_1 v_1) + \frac{V_2^2 - V_1^2}{2} + (Z_2 - Z_1) g\right] + \frac{dQ}{dt}$$

$$\frac{dw_x}{dt} = -0.5 \text{ kg/sec}\left[90 \text{ kJ/kg} + (700 \times 0.19 - 100 \times 0.95) \text{ kJ/kg} + \frac{(5^2 - 7^2) \times 10^{-3}}{2} \text{ kJ/kg}\right] - 58 \text{ kW}$$

$$= 0.5\,[90 + 38 - 0.012] \text{ kJ/sec} - 58 \text{ kW}$$

$$= -122 \text{ kW}$$

b) mass balance

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

$$\frac{A_1}{A_2} = \frac{v_1}{v_2} \cdot \frac{V_2}{V_1} = 3.57$$

$$\frac{d_1}{d_2} = \sqrt{3.57} = 1.89$$

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

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(3) Air at a temperature of 15°C passes through a heat exchanger at a velocity of 30m/sec where its temp is raised to 800°C. It then enters a turbine with the same velocity of 30m/s, and expands until the temp falls to 650°C. On leaving the turbine, the air is taken at a velocity of 60 m/sec to a nozzle where it expands until the temp has fallen to 500°C. If the air flow rate is 2kg/sec. calculate.

a) The rate of heat transfer to the air in the heat exchanger.

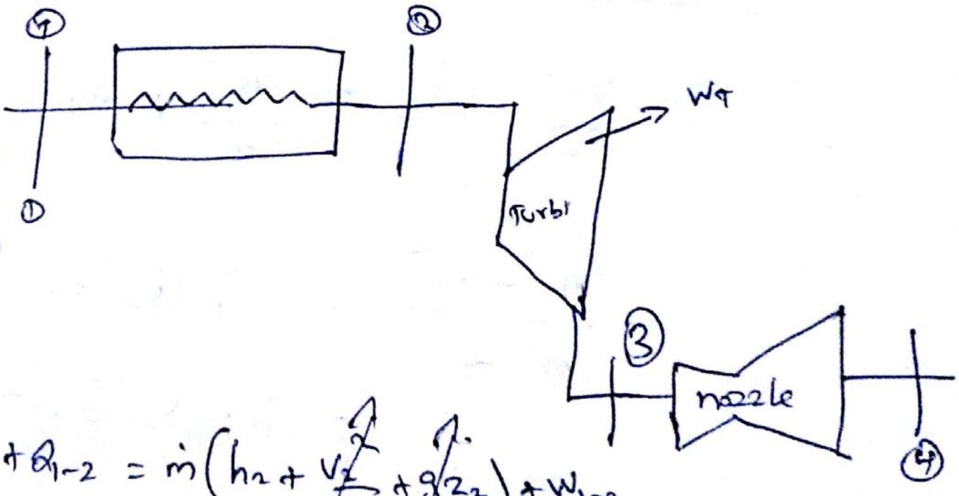
b) The power output from the turbine assuming no heat loss & (c) the velocity at exit from the nozzle, assumming no heat loss. Take the enthalpy of air as $h = C_p t$ where C_p is specific heat equal to 1.005 kJ/kgK and t is the temperature

$T_1 = 15°C \quad T_2 = 800°C$

$V_1 = 30 m/s \quad V_2 = 30 m/s$

$T_3 = 650°C \quad V_3 = 60 m/s$

$T_4 = 500°C \quad V_4 = ?$



Heat exchanger:

$$\dot m \left(h_1 + \cancel{\frac{V_1^2}{2}} + \cancel{g z_1}\right) + Q_{1-2} = \dot m \left(h_2 + \cancel{\frac{V_2^2}{2}} + \cancel{g z_2}\right) + W_{1-2}$$

$$\dot m h_1 + Q_{1-2} = \dot m h_2$$

$$Q_{1-2} = \dot m (h_2 - h_1) \qquad C_p = 1.005 \text{ kJ/kgK}$$

$$= \dot m C_p (t_2 - t_1)$$

$$= 1580 \text{ kJ/sec}$$

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E.E for the turbine

$$\dot{m}\left(\frac{V_2^2}{2} + h_2\right) = \dot{m}\left(h_3 + \frac{V_3^2}{2}\right) + W_T$$

$$\frac{V_2^2 - V_3^2}{2} + (h_2 - h_3) = W_T/\dot{m}$$

$$\frac{(30^2 - 60^2)\times 10^{-3}}{2} + 1.005\,(800-650) = W_T/\dot{m}$$

$$W_T/\dot{m} = -1.35 + 150.75$$

$$\boxed{W_T/\dot{m} = 149.4 \text{ KJ/kg}}$$

$$W_T = 149.4 \times 2 \text{ KJ/sec}$$

$$\boxed{W_T = 298.8 \text{ kW}}$$

nozzle:

$$\frac{V_3^2}{2} + h_3 = \frac{V_4^2}{2} + h_4$$

$$\frac{V_4^2 - V_3^2}{2} = C_p\,(t_3 - t_4)$$

$$= 1.005\,(650-500) \times 10^3 \times 2$$

$$= 301.5 \times 10^3 \text{ m}^2/\text{s}^2$$

$$V_4^2 = 30.15 \times 10^4 + 0.36 \times 10^4$$

$$= 30.51 \times 10^4 \text{ m}^2/\text{s}^2$$

$$\boxed{V_4 = 554 \text{ m/s}}$$