Steady flow Process :-

Steady flow - the rates of flow of mass and energy across the control surface are Constant.

In a System, the rate of flow of working fluid is constant with respect to time, then the system is known as steady flow system.

Energy :-

i) **stored energy** - contained within the system boundaries
Eg: P.E, K.E, I.E.

ii) **Transmit energy** - crosses the Boundary of a system.
Eg: Heat, work.

Potential Energy :-

Possessed by a system because of its height.

$$P.E = mgh$$

$$P.E = mg.z$$

Kinetic Energy :-

Possessed by a system by virtue of motion.

$$K.E = \frac{1}{2} mv^2$$

$$K.E = \frac{1}{2} mc^2$$

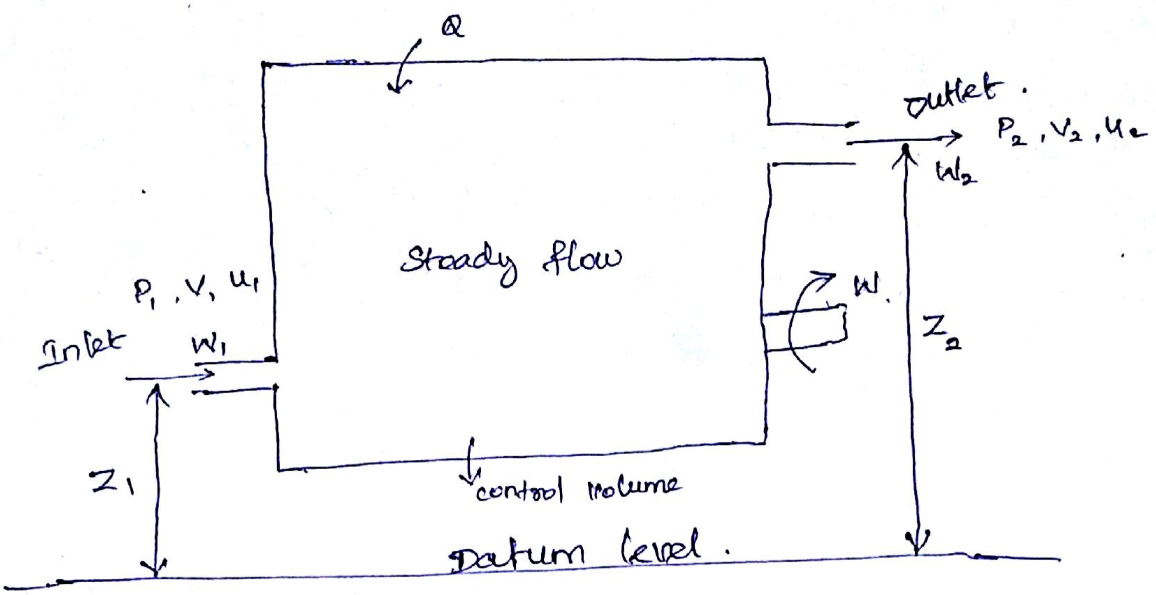
Flow Energy :-

It is the energy associated with the flow of mass across the boundary of a system.

Steady Flow Energy Equation (SFEE)

Assumptions :-

- rate of mass flow through is constant.
- rate of heat transfer is constant.
- rate of work transfer is constant.
- only P.E, K.E, F.E, I.E. consider & no other forms, electrical chemical etc.



Consider as open system through in which the working substance flows as a steady rate.

P_1 P_2 - pressure of the working substance in the system (N/m^2).

V_1 V_2 - specific volume of the working substance (m^3/kg).

u_1 u_2 - internal energy J/kg.

Z_1 Z_2 - datum level for inlet and outlet in m.

Total energy entering the system = P.E + K.E + I.E + F.E + Heat energy

$$= gZ_1 + \frac{C_1^2}{2} + u_1 + P_1V_1 + Q.$$

Total energy leaving the system = P.E + K.E + I.E + F.E + Work

$$= gZ_2 + \frac{C_2^2}{2} + u_2 + P_2V_2 + W$$

First law of thermodynamics

$$E_{in} = E_{out}$$

$$gZ_1 + \frac{C_1^2}{2} + u_1 + P_1V_1 + Q = gZ_2 + \frac{C_2^2}{2} + u_2 + P_2V_2 + W.$$

$$gZ_1 + \frac{C_1^2}{2} + h_1 + Q = gZ_2 + \frac{C_2^2}{2} + h_2 + W$$

Steady flow energy equation. (SFEE)

$$Q - W = g(Z_2 - Z_1) + \frac{1}{2}(C_2^2 - C_1^2) + (h_2 - h_1).$$

Application of Steady flow energy equation.

1. Boiler 2. Condenser 3. Nozzle 4. Turbine 5. Air Compressor 6. Throttling Device.

Boiler :-

P.E & K.E can be neglected. K.E = Small.

$z_1 = z_2$ $c_1 = c_2$ $W = 0$.

$$gz_1 + \frac{c_1^2}{2} + h_1 + Q = gz_2 + \frac{c_2^2}{2} + h_2 + W$$

$$h_1 + Q = h_2$$

$$\boxed{Q = (h_2 - h_1) \text{ KJ}}$$

condenser :-

$W = 0$, $z_1 = z_2$, $c_1 = c_2$.

$$h_1 + Q = h_2$$

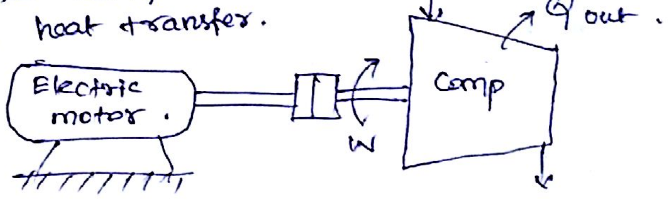
$$\boxed{Q = h_2 - h_1 \text{ KJ}}$$

Compressor & Turbine :-

If the compressor casing is insulated, no heat transfer.

Work is input, so $W_{in} < 0$

Q is output. $Q_{out} < 0$



$\Delta K.E = 0$ $P.E = 0$.

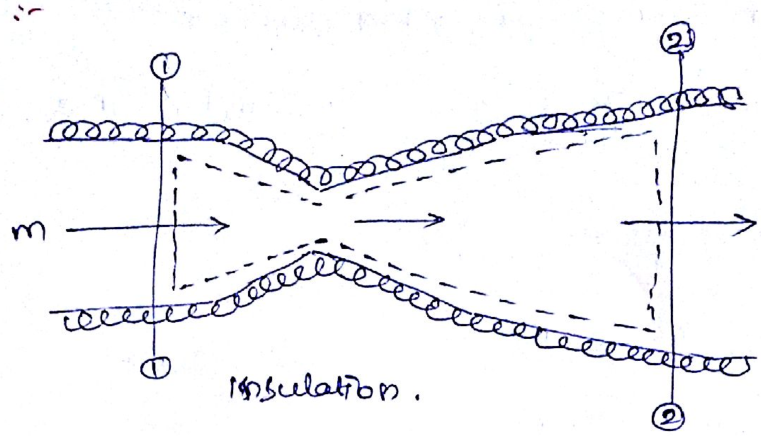
$$gz_1 + \frac{c_1^2}{2} + h_1 + Q = gz_2 + \frac{c_2^2}{2} + h_2 + W.$$

$$h_1 = h_2 + W$$

$$\boxed{W = h_1 - h_2}$$

The workdone increase due to increase in enthalpy. ~~neglect~~ A negative sign indicates that the work is done on the system.

Nozzle :-



Nozzle is a device which increases the velocity or K.E of a fluid at the expense of its pressure drop.

Diffusor increases the pressure of a fluid at the expense of its K.E

$$gz_1 + \frac{c_1^2}{2} + h_1 + Q = gz_2 + \frac{c_2^2}{2} + h_2 + W.$$

Here, $Q = 0$, $W = 0$, $P.E = 0$

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

continuity equation,

$$\frac{A_1}{A_2} = \frac{V_2}{V_1} < 1 \qquad \because \frac{A_1}{A_2} < 1.$$

inlet velocity V_1 is small compared to the outlet velocity V_2.

$$V_2 < V_1 \Rightarrow c_2 < c_1$$

$$h_1 = h_2 + \frac{c_2^2}{2}.$$

$$c_2^2 = 2(h_1 - h_2) \qquad (h_1 - h_2) \text{ is in } J/kg.$$

$$\boxed{C_2 = \sqrt{2(h_1 - h_2)} \ m/s}.$$

Throttling Devices :-

When a fluid flows through a constricted passage, like a partially opened valve, an orifice, there is an appreciable drop in pressure and the flow is said to be throttled. The process of throttling by a partially opened valve on a fluid flowing in an insulated pipe.

$Q = 0$, $W = 0$. P.E is very small and neglected.

$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}.$$

often the pipe velocities in throttling are so low that the

K.E are also negligible.

$$h_1 = h_2$$

Enthalpy of the fluid before throttling is equal to the enthalpy of the fluid after throttling.

Problems :-

Air flows steadily at the rate of 0.5 kg/s through an air compressor entering at 7 m/s velocity, 100 kPa pressure, 0.95 m³/kg volume, and leaving at 5 m/s, 700 kPa pressure, 0.19 m³/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of 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 the outlet pipe diameter.

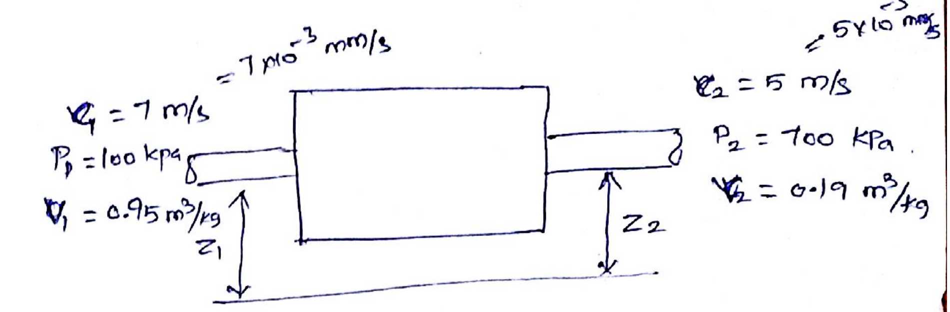
Given :-

$m = 0.5$ kg/s

$\Delta u = 90$ kJ/kg

$Q = -58$ kW.

$u_2 = u_1 + 90$ kJ/kg.



To find :-

Work rate (W) = ?

$\frac{d_1}{d_2} = ?$

1 pa = 1 N/m²

kpa = 10^3 N/m² = 10^{-3} N/mm²

Solution :-

(i) $$m\left[\frac{c_1^2}{2} + gz_1 + u_1 + P_1V_1\right] + Q = m\left[\frac{c_2^2}{2} + gz_2 + u_2 + P_2V_2\right] + W.$$

$$-W = m\left[\frac{c_2^2 - c_1^2}{2} + g(z_2 - z_1) + (u_2 - u_1) + P_2V_2 - P_1V_1\right] - Q$$

$$= 0.5\left[\frac{5^2 - 7^2}{2}\times10^{-3} + 9.81(0) + (90 + u_1 - u_1) + (700\times0.19 - 100\times0.95)\times10^{-3}\right] + 58$$

$$= 0.5\left[-0.012 + 0 + 38 + 98\right].$$

$W = -122$ kW

Rate of work input is 122 kW.

ii) $$m = \frac{A_1C_1}{V_1} = \frac{A_2C_2}{V_2} \Rightarrow \frac{A_1}{A_2} = \frac{C_2\cdot V_1}{C_1\cdot V_2} = \frac{5\times0.95}{0.19\times7}$$

$$\frac{\frac{\pi}{4}d_1^2}{\frac{\pi}{4}d_2^2} = 3.57. \Rightarrow \frac{d_1}{d_2} = \sqrt{3.57}$$

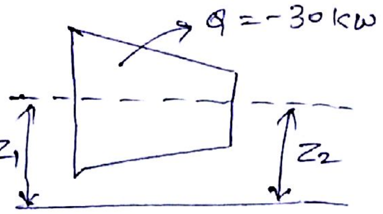
$$\boxed{\frac{d_1}{d_2} = 1.89 \text{ mm}}.$$

(2) In a steam powerplant, steam flows steadily from the steam generate to the turbine. In order to increases the velocity of steam before striking the turbine blades, it passes through a horizontal nozzle having an inlet area of 0.1 m^2. Steam at 1000 kpa and 400°c enters the nozzles with a velocity of 70 m/s. The steam leaves the nozzle at 300 kpa at 300°c. There is a heat loss of 30 kW while steam passing through it. Properties of steam are follows: Determine the mass flow rate of steam the exit velocity and the exit area of the nozzle.

Pressure kPa	Temperature in °c	Enthalpy kJ/kg	Specific Volume m^3/kg
1000	400	3263.9	0.292
300	300	3069.3	0.875

Steady Flow Energy Equation:-

$$m\left[h_1 + \frac{C_1^2}{2} + gz_1\right] + Q = m\left[h_2 + \frac{C_2^2}{2} + gz_2\right] + W$$



$Z_1 = Z_2$

$W = 0$

$$m_1 = \frac{A_1 V_1}{v_1} = \frac{0.1 \times 70}{0.292} = 23.97 \text{ kg/s}$$

$$m\left[h_1 + \frac{C_1^2}{2}\right] + Q = m\left[h_2 + \frac{C_2^2}{2}\right]$$

$$23.97\left[3263.9 \times 10^3 + \frac{70^2}{2}\right] - 30 \times 10^3 = 23.97\left[3069.3 \times 10^3 + \frac{V_2^2}{2}\right]$$

$$\boxed{V_2 = 625.78 \text{ m/s}}$$

$$m_2 = \frac{A_2 V_2}{v_2} = \frac{A_2 \times 625.78}{0.875}$$

$$m_1 = m_2 = 23.97$$

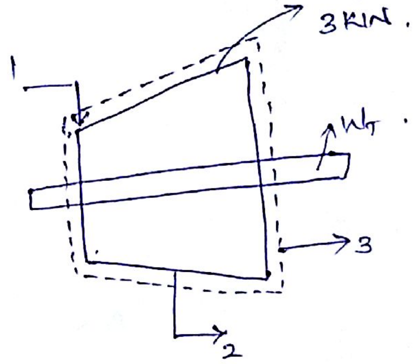
$$23.97 = \frac{A_2 \times 625.78}{0.875}$$

$$\boxed{A_2 = 0.035 \text{ m}^2}$$

(3) In an combined power and process plant steam is generated at 20 MPa and 500°c at a rate of 120 kg/s and is expanded through a turbine. While the steam is expanded in the turbine, 30 kg/s of steam at 5 MPa and 300°c is extracted for process work from the middle of the turbine. The remaining steam is further expanded and exists the turbine as liquid - vapour mixture with 90% quality at 75 kPa. There is a heat loss to the surroundings at the rate of 3 kW. Properties of steam are as follows.

Pressure (kPa)	Temperature (°c)	Enthalpy (kJ/kg)
20,000	500	3238.2
5000	300	2924.5

The specific enthalpy of water at 75 kPa and 90% quality is 2514.4 kJ/kg. Assuming there is no change in kinetic energy and potential energy, determine the total power output of the turbine.



Given:-

$m_1 = 120$ kg/s

$m_2 = 30$ kg/s

$m_3 = ?$

$m_1 = m_2 + m_3$

$m_3 = m_1 - m_2 = 120 - 30 = 90$ kg/s

$\because$ K.E = 0, P.E = 0.

$$m\left(h_1 + gz_1 + \frac{C_1^2}{2}\right) + Q = m\left[\left(h_2 + gz_2 + \frac{C_2^2}{2}\right) + \left(h_3 + gz_3 + \frac{C_3^2}{2}\right)\right] + W.$$

K.E = $C_1 = 0$, P.E $\Rightarrow z_1 = 0$

$$m_1 h_1 + Q_1 = m\left[h_2 + h_3\right] + W.$$

$$m_1 h_1 + Q_1 = m_2 h_2 + m_3 h_3 + W$$

$$120 \times 3238.2 \times 10^{-3} - 3 \times 10^3 = 30 \times 2924.5 \times 10^{-3} + 90 \times 2924.5 \times 10^{-3} + W.$$

$W = 74550000.$

$\boxed{W = 74.55 \text{ MW}}$

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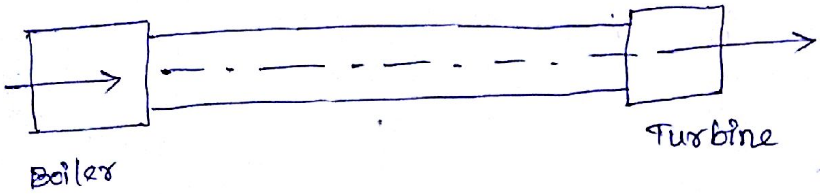
In a steam power station, steam flow steadily through a 0.2 m diameter pipeline from the boiler to the turbine. at the boiler end, the steam conditions are found to be: $P = 4$ MPa, $t = 400°c$, $h = 3213.6$ KJ/kg and $v_1 = 0.073\ m^3/kg$. At the turbine end, the conditions are found to be: $P = 3.5$ MPa, $t = 392°c$, $h = 3202.6$ KJ/kg and $v = 0.084\ m^3/kg$. There is a heat loss of 8.5 KJ/kg from the pipeline. Calculate the steam flow rate.



$$\frac{A_1 C_1}{V_1} = \frac{A_2 C_2}{V_2} \qquad A_1 = A_2.$$

$$C_2 = \frac{A_1 C_1}{V_1} \times \frac{V_2}{A_2} = \frac{0.084}{0.073} C_1$$

$$\boxed{C_2 = 1.15\, C_1}$$

There is no change in datum, so change in potential energy will be zero. $W = 0$. $Z_1 = Z_2$.

$$h_1 + \frac{C_1^2}{2} + Q = h_2 + \frac{C_2^2}{2}.$$

$$h_1 - h_2 + Q = \frac{C_2^2 - C_1^2}{2}$$

$$3213.6 - 3202.6 - 8.5 = \frac{(1.15 C_1)^2 - C_1^2}{2}$$

$$(2 \times 2.5) = C_1^2 (1.15 - 1)$$

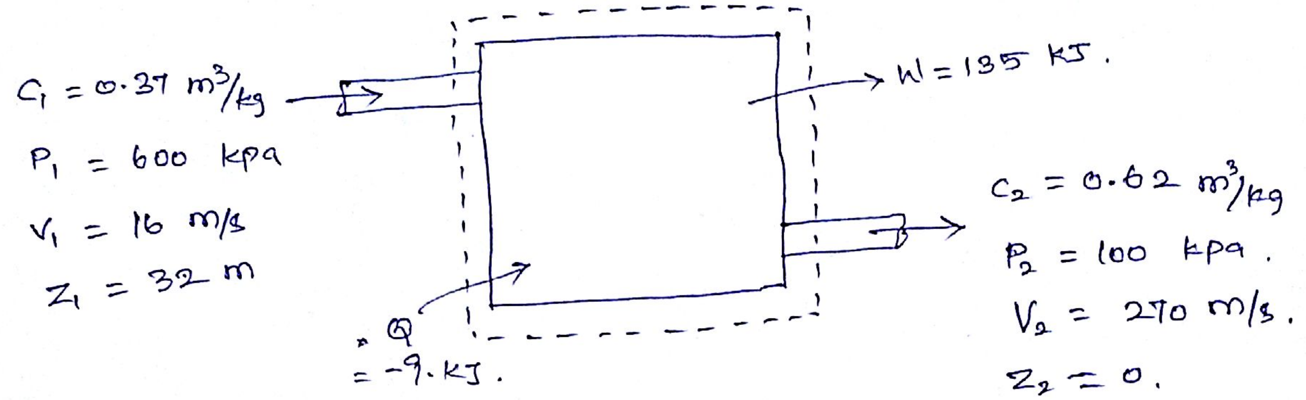
$$C_1^2 = 15650\ m^2/s^2.$$

$$\boxed{C_1 = 125.1\ m/s}$$

Mass flow rate $\dot{m} = \frac{A_1 C_1}{V_1} = \frac{\pi/4\,(0.2)^2 \times 125.1}{0.073}$

$$\boxed{\dot{m} = 53.8\ kg/s}$$

In a steady flow apparatus, 135 KJ of work is done by each kg of fluid. The specific volume of the fluid, pressure and velocity at the inlet are 0.37 m^3/kg, 600 kpa and 16 m/s respectively. The inlet is 32 m above the floor and the discharge pipe is at floor level. The discharge conditions are 0.62 m^3/kg, 100 kpa and 270 m/s. The total heat loss between the inlet and discharge is 9 KJ/kg of fluid. In flowing through this apparatus, does the specific internal energy increase or decrease and by how much?



To find :-

$u_1 - u_2 = ?$

Increase or decrease.

Solution :-

$$u_1 + P_1V_1 + \frac{C_1^2}{2} + Z_1 g + Q = u_2 + P_2V_2 + \frac{V_2^2}{2} + gZ_2 + W.$$

$$u_1 - u_2 = (P_2V_2 - P_1V_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1) + W - Q.$$

$$= (1\times0.62 - 6\times0.37)\times10^{3} + \left(\frac{270^2 - 16^2}{2}\right)\times10^{-3} + 9.81(-32\times10^{-3}) + 135 - (-9)$$

$$= 20.136 \text{ KJ/kg}.$$

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