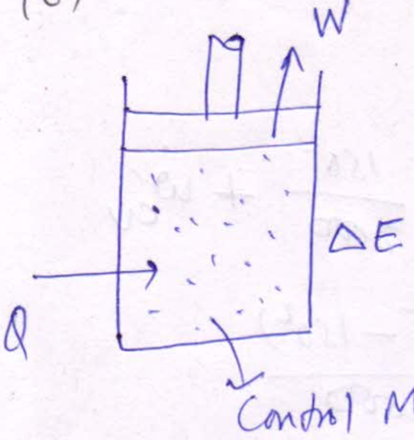
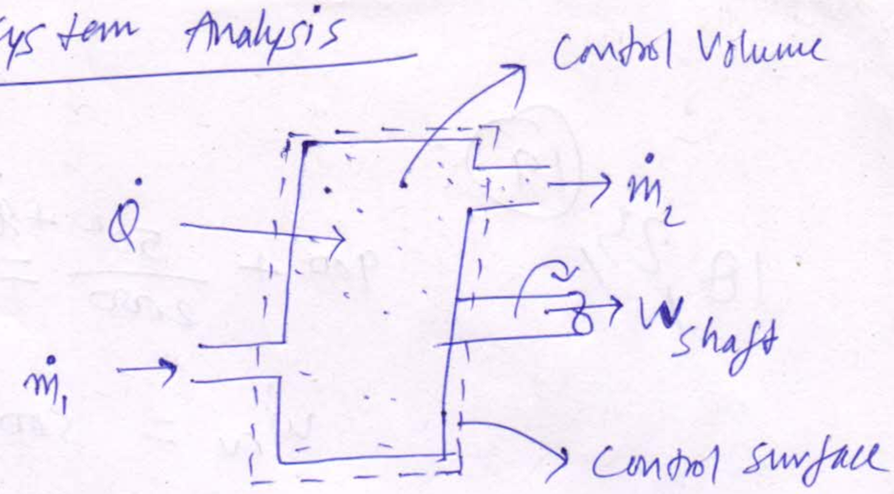
18,

Open System Analysis

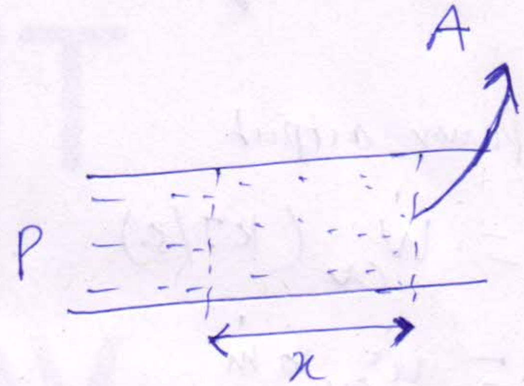




Closed system

$$\boxed{Q = W + \Delta E}$$

Open System



Flow Work:

Flow Work $W = F \times x$

$W = P \times A \times x = P \times V$

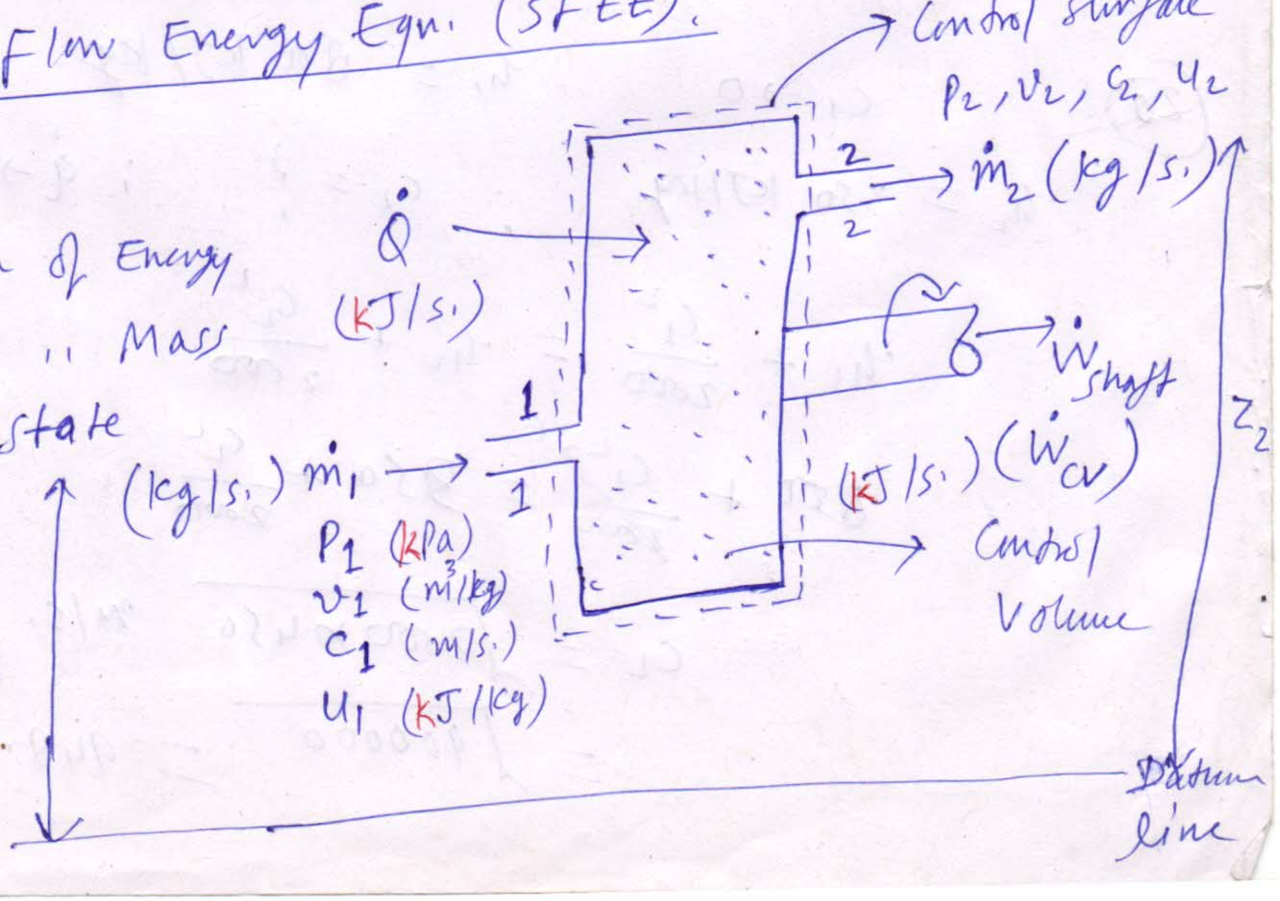
Flow work per unit Mass Flow

$$\boxed{w = p \times v}$$

Steady Flow Energy Eqn. (SFEE):

Assumptions:

1. conservation of Energy
2. " " Mass
3. Steady state



Applying the conservation of Energy at inlet & exit:

$$\dot{m}_1 \left\{ u_1 + p_1 v_1 + \frac{c_1^2}{2} + g z_1 \right\} + \dot{Q}$$
$$= \dot{m}_2 \left\{ u_2 + p_2 v_2 + \frac{c_2^2}{2} + g z_2 \right\} + \dot{W}_{shaft}$$

Applying conservation of Mass: $\dot{m}_1 = \dot{m}_2 = \dot{m}$

$$\dot{m} \left(u_1 + p_1 v_1 + \frac{c_1^2}{2} + g z_1 \right) + \dot{Q}$$
$$= \dot{m} \left(u_2 + p_2 v_2 + \frac{c_2^2}{2} + g z_2 \right) + \dot{W}_{shaft}$$

$$u_1 + p_1 v_1 + \frac{c_1^2}{2} + g z_1 + \frac{\dot{Q}}{\dot{m}} = u_2 + p_2 v_2 + \frac{c_2^2}{2} + g z_2 + \frac{\dot{W}_{shaft}}{\dot{m}}$$

$$\boxed{u_1 + p_1 v_1 + \frac{c_1^2}{2} + g z_1 + \dot{q} = u_2 + p_2 v_2 + \frac{c_2^2}{2} + g z_2 + \dot{w}_{shaft}}$$

$$\boxed{h_1 + \frac{c_1^2}{2} + g z_1 + \dot{q} = h_2 + \frac{c_2^2}{2} + g z_2 + \dot{w}_{shaft}}$$

ere $h_1 \Rightarrow J/kg$; $c_1 \Rightarrow m/s$.

$z_1 \Rightarrow m$. ; $\dot{q} \Rightarrow J/kg$; $\dot{w}_{shaft} \Rightarrow J/kg$

f h_1 is given in kJ/kg ; $\dot{q} \Rightarrow kJ/kg$, w_{shaft} als

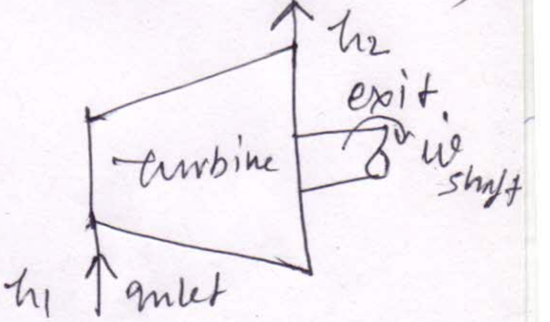
$$\Rightarrow \boxed{h_1 + \frac{c_1^2}{2000} + \frac{g z_1}{1000} + \dot{q} = h_2 + \frac{c_2^2}{2000} + \frac{g z_2}{1000} + \dot{w}_{shaft}}$$

Applications of SFEE: ① Turbine ② Compressor ③ Nozzle ④ Boiler ⑤ Diffuser

① Turbine
- Its a Work (Power) producing device
- Adiabatic
- $\Delta KE \to 0$; $\Delta PE \to 0$
- Steady State

$$h_1 + \cancelto{0}{\frac{C_1^2}{2}} + \cancelto{0}{gz_1} + \cancelto{0}{\dot{q}} = h_2 + \cancelto{0}{\frac{C_2^2}{2}} + \cancelto{0}{gz_2} + \dot{w}_{cv}$$

$(\dot{w}_{shaft})$



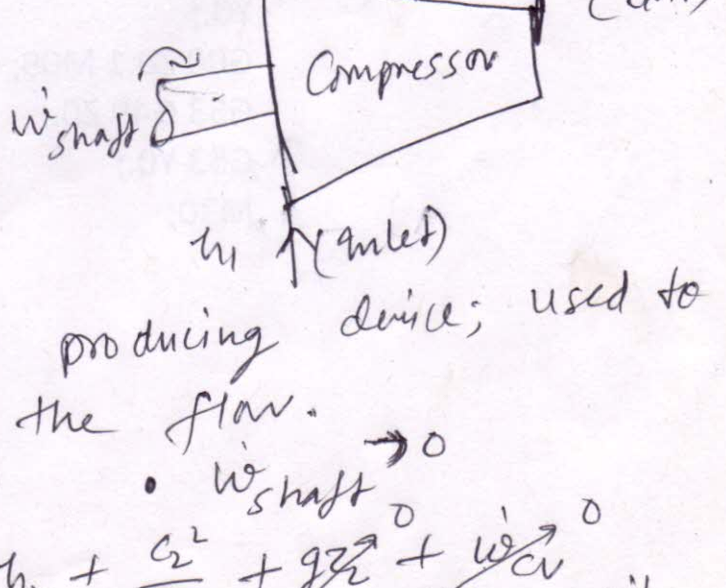
$$h_1 = h_2 + \dot{w}_{cv}$$

$$\boxed{\dot{w}_{cv} = h_1 - h_2}$$

② Compressor
- Its a work consuming device & used to increase the pressure of a gas.
- Adiabatic
- $\Delta KE \to 0$; $\Delta PE \to 0$
- Steady State

$$h_1 + \cancelto{0}{\frac{C_1^2}{2}} + \cancelto{0}{gz_2} + \cancelto{0}{\dot{q}} + \dot{w}_{cv} = h_2 + \cancelto{0}{\frac{C_2^2}{2}} + \cancelto{0}{gz_2}$$

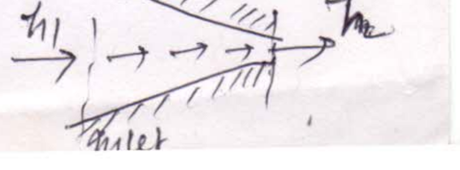
$$\boxed{\dot{w}_{cv} = h_2 - h_1}$$



③ Nozzle: • Its a velocity producing device; used to increase the velocity of the flow.
- Adiabatic
- $\Delta PE \to 0$
- $\dot{w}_{shaft} \to 0$

$$h_1 + \frac{C_1^2}{2} + \cancelto{0}{gz_1} + \cancelto{0}{\dot{q}} = h_2 + \frac{C_2^2}{2} + \cancelto{0}{gz_2} + \cancelto{0}{\dot{w}_{cv}}$$

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



II law of Thermodynamics

I law is just a quantitative law; it doesn't tell anything about the quality of energy.
Also the processes always occur in a particular dirn.
<u>like:</u> K.E. → Brakes → Heat ; but reverse can't hold good.
So there is a need of another law to tell about the direction of any thermodynamics process; this direction of any process is indicated by II law of thermo. thats why it is also called as directional law.

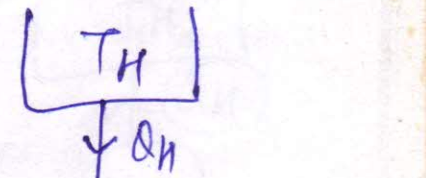
<u>Thermal Energy Reservoir:</u> It is a reservoir of infinite heat capacity. Its temp. doesn't change; irrespective of the huge amount of energy extracted from it.
→ Heat source (Furnace, Sun etc.)
→ Heat sink (sea, Pond ~~etc.~~, atmosphere etc.)

<u>Heat Engine:</u> It is a device operating in a thermodynamics cycle; which produces work continuously, on observing heat from a Heat source.

$$\eta_{H.E.} = \frac{\text{Desired Effect}}{\text{Heat Input}}$$

$$\eta_{H.E.} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$\boxed{\eta_{H.E.} = 1 - \frac{Q_L}{Q_H}}$$



<u>Heat Engine</u>

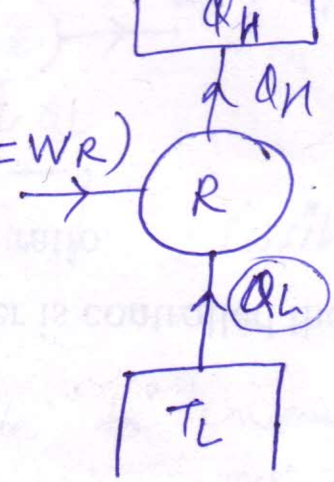
For a <u>Reversible Heat Engine (Carnot Engine)</u>

$$\boxed{\eta_{H.E.} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}}$$

⇒ For a particular temp. limits; the maximum efficiency is of a Reversible H.E. (Carnot H.E.).

~~Ref~~ Refrigerator: It is device operating in a thermodynamic cycle; used to maintain a particular space at a temp. lower than surroundings. It works as a Reversed H.E.

It is a work consuming device.



$(Q_H - Q_L = W_R)$

$$(COP)_R = \frac{\text{Desired Effect}}{\text{Energy Input}}$$

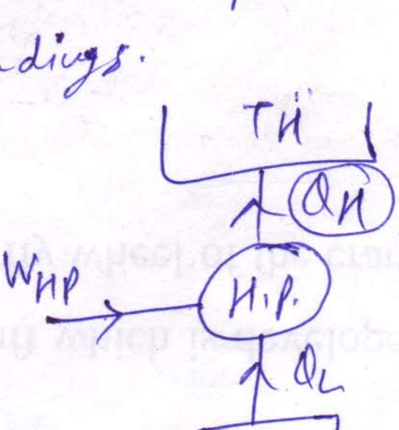
$$= \frac{Q_L}{W_R} = \frac{Q_L}{Q_H - Q_L}$$

$$\boxed{(COP)_R = \frac{Q_L}{Q_H - Q_L}}$$

For a Reversible Refrigerator (Carnot Refrigerator)

$$\boxed{COP_R = \frac{T_L}{T_H - T_L}}$$

Heat ~~Engine~~ Pump (HE) It is a device operating in a thermo. cycle; used to maintain a particular space at a temp. Higher than that of surroundings.



$$(COP)_{HP} = \frac{\text{Desired Effect}}{\text{Energy Input}}$$

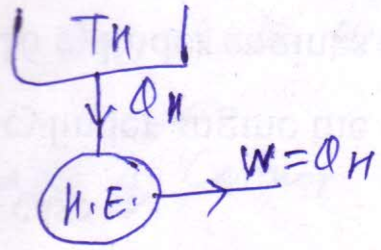
$$= \frac{Q_H}{W_{HP}} = \frac{Q_H}{Q_H - Q_L}$$

$$\boxed{COP_{HP} = \frac{T_H}{T_H - T_L}}$$

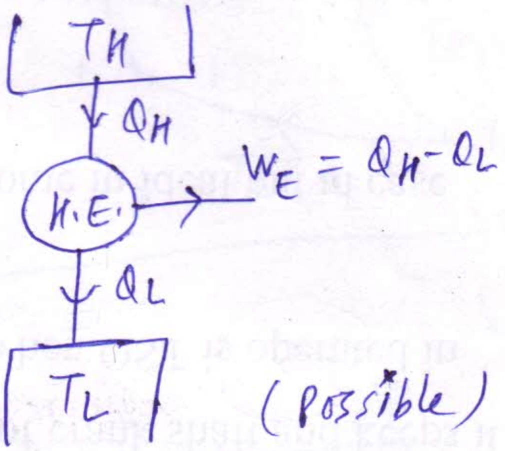
For a Rev. H.P. (Carnot HP) $(COP)_{HP}$

⇒ It also works as a reversed H.E.

Kelvin Plank Stmt : It is impossible to construct a Heat Engine operating in a cycle; which produces work continuously; by ~~Observing~~ exchanging Heat with a single TER.



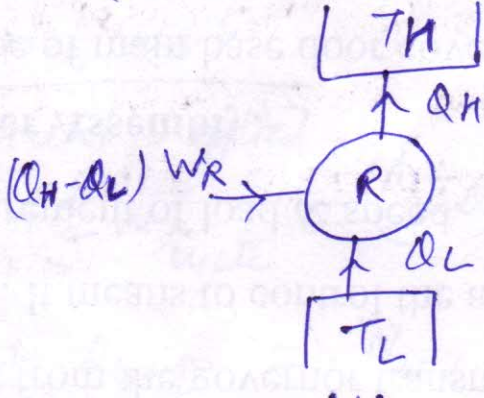
impossible



(possible)

Clausius Statement: It is impossible to construct a device operating in a cycle; which continuously transfers heat from a lower temp. body to a higher temp. body; without any external Energy input.

impossible



Possible

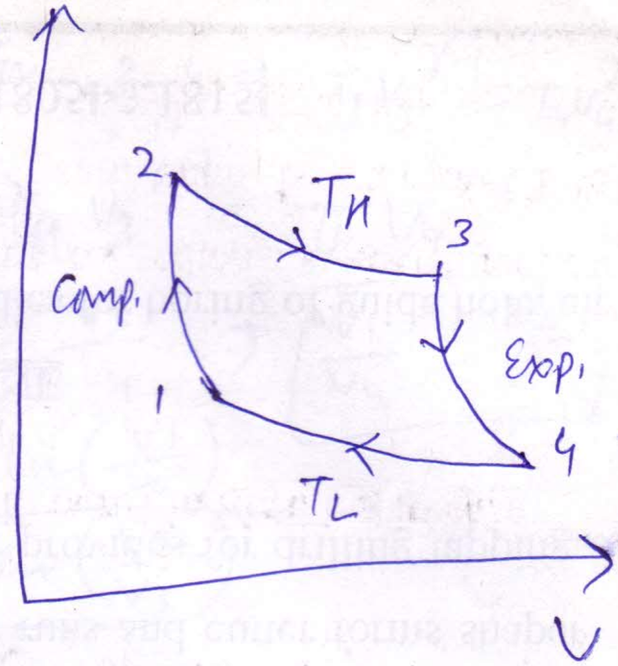
Carnot's Cycle:

1-2 $\Rightarrow$ Rev. Adiab. Compressn

2-3 $\Rightarrow$ Rev. Isoth. Heat Addn

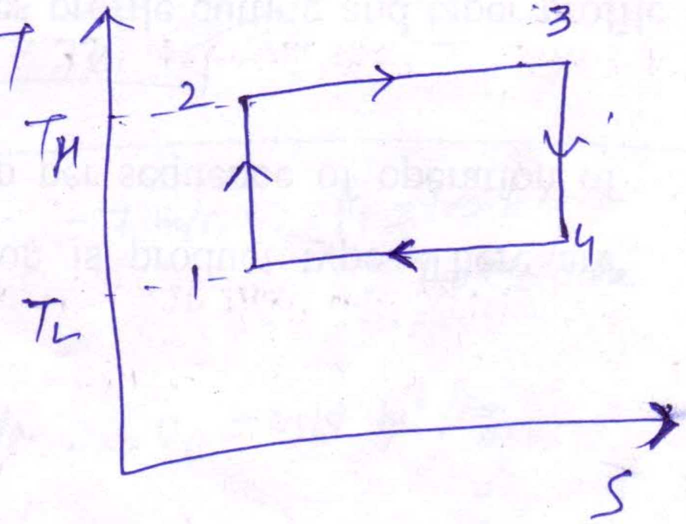
3-4 $\Rightarrow$ Rev. Adiab. Expansion

4-1 $\Rightarrow$ Rev. Isoth. Heat Rejn.



In case of Carnot H.E.,

All the processes are reversible processes; as mentioned above.



Now Efficiency of Carnot Engine:

$$\eta_{E_{carnot}} = \frac{\text{Net Work}}{\text{Heat supplied}}$$

Net Work $\quad (\Sigma W)_{cycle} = (\Sigma Q)_{cycle}$

$$= Q_{2-3} + Q_{4-1} = W_{2-3} + W_{4-1}$$

$$= mRT_H \ln\left(\frac{V_3}{V_2}\right) + mRT_L \ln\left(\frac{V_1}{V_4}\right)$$

& Heat supplied $= Q_{2-3} = mRT_H \ln\left(\frac{V_3}{V_2}\right)$

$$\left[\eta_{E_{carnot}} = 1 + \frac{T_L}{T_H} \frac{\ln\left(\frac{V_1}{V_4}\right)}{\ln\left(\frac{V_3}{V_2}\right)}\right]$$

For 1-2 $\Rightarrow T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \Rightarrow T_L V_1^{\gamma-1} = T_H V_2^{\gamma-1}$

$$\left[\frac{T_L}{T_H} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}\right]$$

For 3–4 $\Rightarrow$ $T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$

$$T_H V_3^{\gamma-1} = T_L V_4^{\gamma-1}$$

$$\frac{T_L}{T_H} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow \frac{V_2}{V_1} = \frac{V_3}{V_4} \Rightarrow \boxed{\frac{V_1}{V_4} = \frac{V_2}{V_3}}$$

$$\eta_{E_{Carnot}} = 1 - \frac{T_L}{T_H} \cdot \frac{\ln\left(\frac{V_1}{V_4}\right)}{\ln\left(\frac{V_2}{V_3}\right)}$$

$$\boxed{\eta_{E_{Carnot}} = 1 - \frac{T_L}{T_H}}$$

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(22) $\dot{m} = 0.5$ kg/s. ; $c_1 = 7$ m/s. ; $P_1 = 100$ kPa $= 100\times10^3$ Pa

$v_1 = 0.95$ m^3/kg

$c_2 = 5$ m/s. ; $P_2 = 700\times10^3$ Pa ; $v_2 = 0.19$ m^3/kg

$u_2 - u_1 = 90$ kJ/kg

$$\dot{Q} = 58 \text{ kW} = 58000 \text{ J/s.}$$

$$\dot{q} = \frac{58000}{\dot{m}} = \frac{58000}{0.5} = 116000 \text{ kJ/kg}$$

$$\dot{w}_{cv} = ?$$

$$\left(u_1 + P_1 v_1 + \frac{c_1^2}{2}\right) + \dot{w}_{cv} = \left(u_2 + P_2 v_2 + \frac{c_2^2}{2}\right) + \dot{q}$$

$$100\times10^3 \times 0.95 + \frac{7^2}{2} + \dot{w}_{cv} = (u_2 - u_1) + 700\times10^3 \times 0.19 + \frac{5^2}{2} + 116000$$

$$10^5 \times 0.95 + \frac{49}{2} + \dot{w}_{cv} = 90\times10^3 + 7\times10^5 \times 0.19 + \frac{25}{2} + 116000$$

$$\dot{w}_{cv} = 90\times10^3 + 0.38\times10^5 + \frac{25}{2} + 116\times10^3 - \frac{49}{2} \simeq 244\times10^3 - 12$$