First Law for closed systems

For a Cycle : $\oint \delta Q = \oint \delta W$

or $\sum Q = \sum W$

For a nonflow process : $\delta Q - \delta W = dE = d\left(U + \frac{1}{2}mC^2 + mgh\right)$

(per unit mass) or $\delta q - \delta w = de = d\left(u + \frac{1}{2}c^2 + gh\right)$ [kJ]

$\delta q - \delta w = du$ (if KE, PE ≈ 0)

$\boxed{\text{or}}$ $Q - W = E_2 - E_1$ [kJ]

or $Q - W = U_2 - U_1$ (if KE & PE ≈ 0)

per unit mass $q - w = u_2 - u_1$

$\boxed{\text{or}}$ $\dot{Q} - \dot{W} = \frac{dE}{dt} = \frac{d}{dt}\left[U + \frac{1}{2}mC^2 + mgz\right]$ [kW]

or $\dot{Q} - \dot{W} = \frac{dU}{dt} + \frac{1}{2}m\frac{d}{dt}(C^2) + mg\frac{dz}{dt}$

$\frac{d}{dt}(C^2) = 2C\frac{dC}{dt} = 2Ca$

$= \frac{dU}{dt} + \frac{d}{dt}\left(\frac{1}{2}mC^2\right) + \frac{d}{dt}(mgz)$

rate of change of internal energy

(wt x vert. vel.)

Conservation of energy statement

(Rate of Heat transfer) − (Rate of Work done) = Rate of change of Internal Energy + Rate of change of Kinetic Energy + Rate of Change of potential Energy

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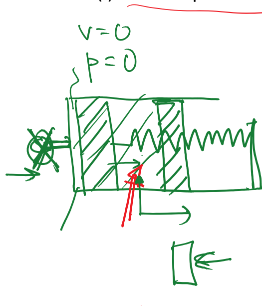
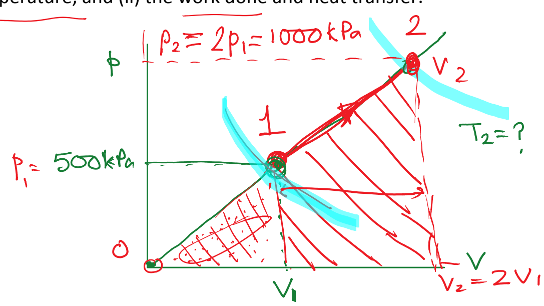
Isentropic ≡ Reversible + adiabatic

A vertical piston-cylinder has a linear spring mounted so that at zero cylinder volume, the balancing pressure inside the cylinder is zero. The cylinder is charged with 0.25 kg of air at 500 kPa and 300 K. Heat is now added so that the volume doubles. Show the process on the p-V diagram. Also find (i) the final pressure and temperature, and (ii) the work done and heat transfer.

$V_1 = \frac{m R_{air} T}{P_1} = \frac{0.25 \times 0.287 \times 300}{500} = 0.043 \ m^3$





$W = \frac{1}{2}(500 + 1000) \times (2V_1 - V_1) = 750 \times 0.043 = 32.25$ kJ

$Q - W = \Delta U \Rightarrow Q = \Delta U + W$

$\Delta U = m C_v \times \Delta T$
$= 0.25 \times 0.718 \times (1200 - 900)$
$= 161.43$ kJ

$C_v = \frac{R}{k-1} = \frac{0.287}{1.4-1} = 0.718 \ \frac{kJ}{kg K}$

To find $T_2 \Rightarrow \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

$\Rightarrow T_2 = 4T_1 = 1200$ K

$\therefore Q = (161.43 + 32.25) = 193.7$ kJ

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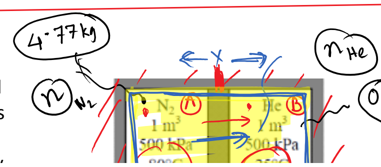
An insulated Rigid cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states as shown in the figure. The two chambers are separated by a conducting Copper wall that is held in its position by a pin. Find the final temperature and pressure of each chamber if (a) the copper wall is held in position by

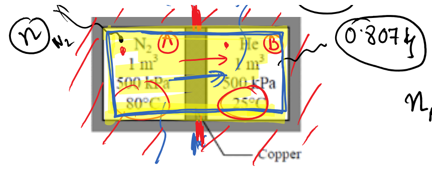


$n_A = \frac{m_A}{M} =$

$m = \frac{P_{1A} V_{1A}}{} \times$

An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states as shown in the figure. The two chambers are separated by a conducting Copper wall that is held in its position by a pin. Find the final temperature and pressure of each chamber if (a) the copper wall is held in position by the pin, and if (b) the pin is removed.

[(a) p_N=467 kPa, p_{He}=826 kPa, T_f= 57°C, (b) 510.7 kPa]



$$n_A = \frac{P_{1A} V_{1A}}{R_u T_{1A}} = \frac{500 \times 1}{8.315 \times 353} = 0.17 \text{ kmol.}$$

$n_B = 0.201$ kmol.

$$\boxed{\frac{n_B}{n_A} = \frac{.201}{.17} = 1.18}$$

Choosing the N_2 + He gas as our system, let us apply the first law

$$Q - W = \Delta U \quad (KE \approx PE \approx 0)$$

$Q = 0$ (insulated)

$W = 0$ [Rigid cylinder]

$\Delta U = 0$

$\Delta U_A + \Delta U_B = 0$

A

$V_{1A} = 1\,m^3$

$P_{1A} = 500$ kPa

$T_{1A} = 353$ K

$M_A = 28$

$$m_A = \frac{p_{1A} V_{1A}}{R_{N_2} T_{1A}} = 4.77\text{ kg}$$

$$R_{N_2} = \frac{8.315}{28} = 0.297 \frac{kJ}{kg\,K}$$

$$C_{v_{N_2}} = \frac{R_{N_2}}{\gamma - 1} = 0.742 \text{ kJ/kg K}$$

B

$V_{1B} = 1\,m3$

$P_{1B} = 500$ kPa

$T_{1B} = 298$ K

$M_B = 4$

$$m_B = \frac{P_{1B} V_{1B}}{R_{He} T_{1B}} = 0.807 \text{ kg}$$

$$R_{He} = \frac{8.315}{4} = 2.078 \frac{kJ}{kg\,K}$$

$$C_{v_{He}} = \frac{R_{He}}{\gamma - 1} = \frac{2.087}{1.67 - 1} = 3.1 \text{ kJ/kg K}$$

$$m_A C_{v_A} (T_{A2} - T_{A1}) + m_B C_{v_B} (T_{B2} - T_{B1}) = 0$$

T_f T_f

$T_{A2} = T_{B2} = T_f$

$$\Rightarrow m_A C_{vA} T_f + m_B C_{vB} T_f = m_A C_{vA} T_{A1} + m_B C_{vB} T_{B1}$$

$$\text{or} \quad T_f = \frac{m_A C_{vA} T_{A1} + m_B C_{vB} T_{B1}}{m_A C_{vA} + m_B C_{vB}} = 330.2\text{ K}$$

check

$C_{vA} = C_{vN_2}$

$C_{vB} = C_{vHe}$

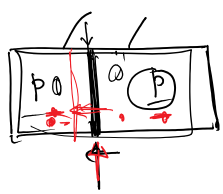
N_2 $$P_{Af} = \frac{m_A R_A T_f}{V_A} = \frac{4.77 \times 0.297 \times 330.2}{1} = 467\text{ kPa}$$

has not changed

$$\boxed{\frac{553.7}{467} = 1.185}$$

He $$P_{Bf} = \frac{m_B R_B T_f}{V_B} = \frac{0.807 \times 2.078 \times 330.2}{1} = 553.7 \text{ kPa}$$

Part 2



$\boxed{P_f} = ?$

$\boxed{V_A + V_B = 2\,m^3}$

$\boxed{T_f = 330.2\text{ K}}$

$n = n_A + n_B = 0.371$

$\Delta U_A + \Delta U_B = 0$

$$\rightarrow \boxed{pV = nRT}$$

$$p_f (V_A + V_B) = 0.371 \times 8.315 \times 330.2$$

$$p_f = \frac{0.371 \times 8.315 \times 330.2}{2} = 509.3\text{ kPa}$$

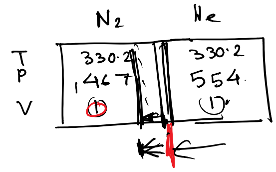
$p_{2A} V_{1A} = p_{3A} V_{3A}$

V_2

	N_2	He
T	330.2	330.2
P	[illegible]	554

$$\frac{p_{2A}V_{2A}}{\cancel{T_{2A}}} = \frac{p_{3A}V_{3A}}{\cancel{T_{3A}}}$$

V_2



$$\frac{p_{2A}V_{2A}}{T_{2A}} = \frac{p_{3A}V_{3A}}{T_{3A}}$$

$$p_{2A}V_{2A} = p_{3A}V_{3A}$$

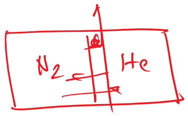
$$467 \times 1\,m^3 = 509.3 \times V_{3A}$$

$$V_{3A} = \frac{467}{509.3} = 0.92\ m^3$$

$$V_{3B} = 1.08\ m^3$$

$$\frac{p_{1A}V_{1A}}{T_{1A}} = \frac{p_{2A}V_{2A}}{T_{2A}} = \frac{p_{3A}V_{3A}}{T_{3A}}$$

Repeat the problem with this condition:
The intervening Copper plate is suddenly ruptured



Find T_f, p_f

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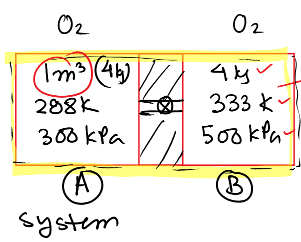
9. A tank has a volume of 1 m^3 with oxygen at 15 °C, 300 kPa. Another tank contains 4 kg oxygen at 60 °C, 500 kPa. The two tanks are connected by a pipe and valve that is opened, allowing the whole system to come to a single equilibrium state with the ambient at 20 °C. Find the final pressure and the heat transfer.

$R_{O_2} = 0.26$ kJ/kg K

$$m_A = \frac{p_A V_A}{R T_A} = \frac{300 \times 1}{0.26 \times 288} = 4\,kg$$

20°C



$V_B = ?$

Considering A + B + Valve + Pipe as our system

$$Q - W = \Delta U$$

$$W = 0; \qquad Q \neq 0$$

$$\boxed{Q = \Delta U}$$

$$\Delta U = m_A C_{vA}(T_f - T_A) + m_B C_{vB}(T_f - T_B)$$

$$= \frac{R_{O_2}}{\gamma - 1}\left[m_A(T_f - T_A) + m_B(T_f - T_B)\right]$$

$$Q = m\frac{R_{O_2}}{\gamma - 1}\left[2T_f - T_A - T_B\right]$$

$$=$$

$m_{total} = 4\,kg$

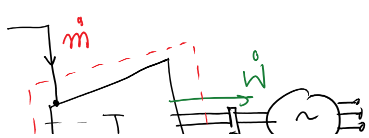
$V_{total} = V_A + V_B$

$T_f = 293\,K$

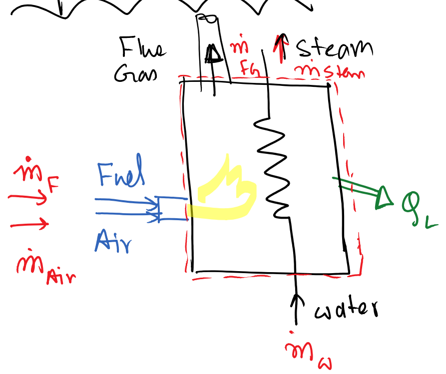
$p_f =$

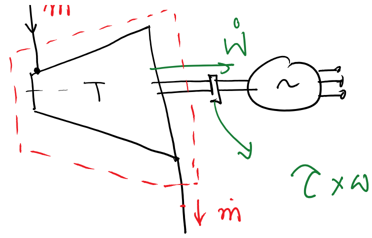
Open Systems

Flow, $\dot{m}$, steam



Open Systems





$$\oint \delta Q = \oint \delta W$$

$$Q - W = \Delta E$$

$$\dot{Q}_{CM} - \dot{W}_{CM} = \frac{dE_{CM}}{dt}$$

All are applicable for control mass (closed system)

Control Mass / Closed system

1. Conservation of Mass: $M_{CM} = const$

$$\boxed{\frac{dM_{CM}}{dt} = 0}$$

2. Conservation of momentum: $\boxed{\frac{d\vec{P}}{dt} = \sum \vec{F}}$

3. Conservation of energy: $\dot{Q} - \dot{W} = \frac{dE}{dt}$

$$\boxed{\frac{d\vec{E}}{dt} = \dot{Q} - \dot{W}}$$

For open systems we need special treatments

Conservation of Mass

$\dot{m}_i = 5$ kg/s

$\dot{m}_e = 7$ kg/s

$\frac{d(M_{cv})}{dt} =$