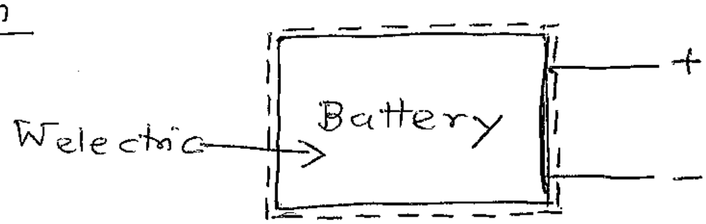
Given
Battery charger of an automobile and a phone

Find
Work (kJ) in each charging process

System



Assumptions
– Uniform voltage and current with time

Basic Equations
N/A

Solution
Electric work for the battery charger

$$W_{electric} = -\int \mathcal{E}\, i\, dt = -\mathcal{E}\, i\, \Delta t$$

(negative sign since work input)

For the automobile battery charger:

$$W_{electric,\,auto} = -(12\,V * 25\,A) * 3600\,s$$
$$= -300\,\frac{J}{s} * 3600\,s$$
$$= -1080{,}000\,J$$

$$\boxed{W_{electric,\,auto} = -1080\,kJ}$$

For the phone battery charger:

$$W_{electric,\,phone} = -(5\,V * 1\,A) * 3600\,s$$
$$= -5\,\frac{J}{s} * 3600\,s$$
$$= -18{,}000\,J$$

$$\boxed{W_{electric,\,phone} = -18\,kJ}$$

Given

Power and speed data for two automobiles

Find

Torque (N-m) for each automobile

System

N/A

Assumptions

N/A

Basic Equations

N/A

Solution

Rotational power of shaft

$$\dot{W}_{shaft} = \tau \omega = \frac{2\pi N \tau}{60}$$

Torque for SUV-1:

$$\tau_1 = \frac{190\ hp * 746\ \frac{W}{hp} * 60\ \frac{s}{min}}{2\pi * 5600\ \frac{rev}{min}}$$

$$\boxed{\tau_1 = 241.7\ N\text{-}m}$$

Torque for SUV-2:

$$\tau_2 = \frac{208\ hp * 746\ \frac{W}{hp} * 60\ \frac{s}{min}}{2\pi * 5500\ \frac{rev}{min}}$$

$$\boxed{\tau_2 = 269.4\ N\text{-}m}$$

SUV-2 should be purchased since $\tau_2 > \tau_1$

Given

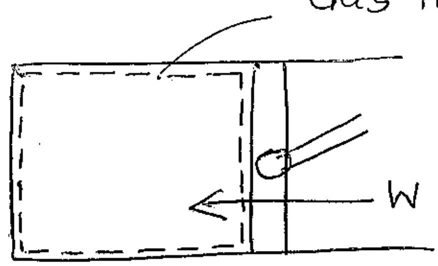
Compression of a gas inside a closed piston – cylinder device

Find

Work (kJ) for the process

System

Gas inside the cylinder is the system



Assumptions

– Quasi – equilibrium process

– ~~Neglect friction between piston and cylinder wall~~

Basic Equations

N/A

Solution

State 1 $\quad P_1 = \text{bar}, \; V_1 = 0.05 \text{ m}^3$

State 2 $\quad V_2 = 0.01 \text{ m}^3, \quad P_2 V_2^{1.5} = P_1 V_1^{1.5}$

$$\Rightarrow P_2 = 1 \text{ bar} * \left(\frac{0.05 \text{ m}^3}{0.01 \text{ m}^3}\right)^{1.5}$$

$$= 11.2 \text{ bar}$$

Boundary work during the process:

$$W_{12} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{\text{constant}}{V^n}\,dV = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{(1 \times 100)\text{ kPa} * 0.05 \text{ m}^3 - (11.2 \times 100)\text{ kPa} * 0.01 \text{ m}^3}{1.5 - 1}$$

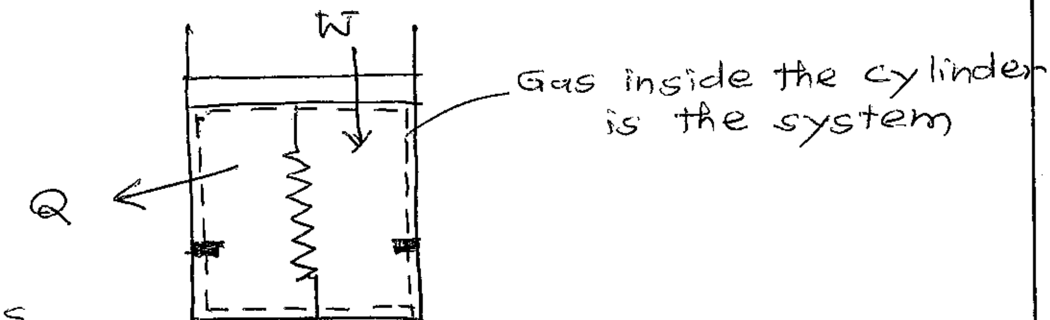
$$\boxed{W_{12} = -12.4 \text{ kJ}}$$

$W < 0$ work done on the gas

Given A gas inside a closed cylinder with spring-loaded piston

Find
(a) Absolute pressure (bar) at States 1 and 2
(b) Absolute pressure (bar) at State 3
(c) P-V diagram
(d) Work (kJ) during the process

System



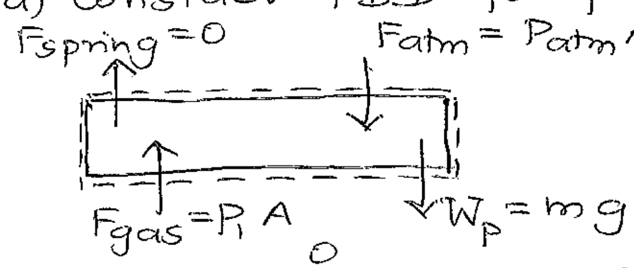
Assumptions
- Closed system (m = constant)
- Quasi-equilibrium process
- ~~Neglect friction between piston and cylinder wall~~
- ~~Ignore area difference between two sides of piston~~
- Gas is ideal

Basic Equations

N/A

Solution

(a) Consider F.B.D for piston at State 1:



$$F_{gas} + \cancel{F_{spring}}^{\,0} = F_{atm} + W_p$$

$$P_1 A = P_{atm} A + mg$$

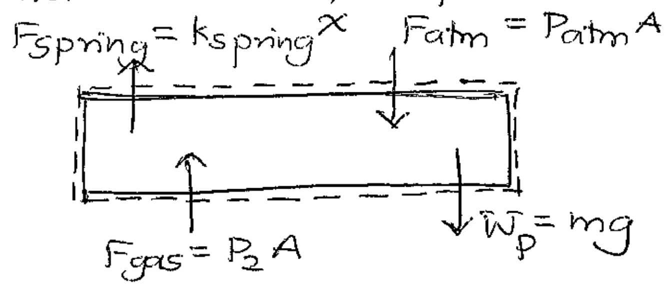
Absolute pressure at State 1:

$$P_1 = P_{atm} + \frac{mg}{A}$$

$$= 100 \text{ kPa} + \left(\frac{20 \text{ kg} * 9.81 \frac{m}{s^2}}{0.03 \text{ m}^2 * 1000} \right) \text{kPa}$$

$$\boxed{P_1 = 106.5 \text{ kPa}}$$

Consider FBD for piston at State 2:



$$F_{gas} + F_{spring} = F_{atm} + W_p$$

$$P_2 A = P_{atm} A + W - k_{spring} x$$

Absolute pressure at State 2:

$$P_2 = P_{atm} + \frac{mg}{A} - \frac{k_{spring} x}{A} = P_1 - \frac{k_{spring} x}{A}$$

Displacement of piston: $x = \frac{V_1 - V_2}{A} = \frac{(0.5 - 0.2) m^3}{0.03 \, m^2}$
$= 10 \, m$

$$P_2 = 106.5 \, kPa - \left(\frac{100 \frac{N}{m} * 10 m}{0.03 \, m^2 * 1000} \right) kPa$$

$$\boxed{P_2 = 73.2 \, kPa}$$

(b) $m_2 = m_3 \Rightarrow \frac{P_2 \cancel{V_2}}{\cancel{R} T_2} = \frac{P_3 \cancel{V_3}}{\cancel{R} T_3}$ (piston constrained at the stops)

Absolute pressure at State 3:

$$P_3 = P_2 * \frac{T_3}{T_2}$$

Similarly, $m_1 = m_2 \Rightarrow \frac{P_1 V_1}{\cancel{R} T_1} = \frac{P_2 V_2}{\cancel{R} T_2}$

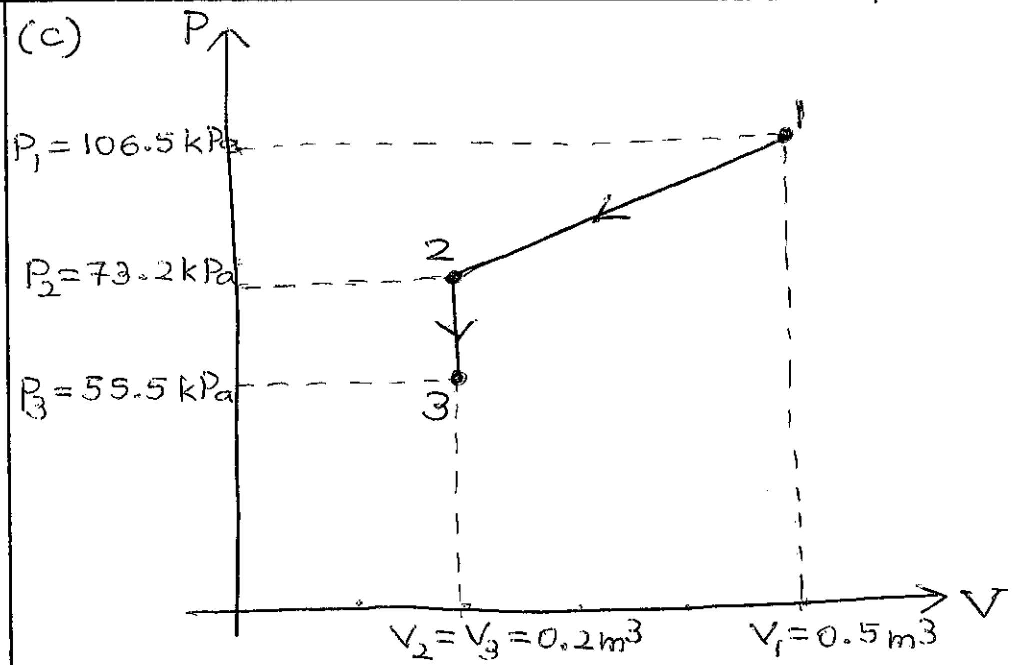
Absolute temperature at State 2:

$$T_2 = T_1 * \frac{P_2}{P_1} * \frac{V_2}{V_1} = 1200 \, K * \frac{73.2 \, kPa}{106.5 \, kPa} * \frac{0.2 \, m^3}{0.5 \, m^3}$$
$\cong 330 \, K$

$$P_3 = 73.2 \, kPa * \frac{250 \, K}{330 \, K}$$

$$\boxed{P_3 = 55.5 \, kPa}$$

(c)



(d) Boundary work during the process:

$$W_{13} = W_{12} + W_{23} = \int_{V_1}^{V_2} P\,dV + \cancel{\int_{V_2}^{V_3} P\,dV}^{\,0}$$

$$= \text{Area under the process curve}$$

$$= \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$$

$$= \frac{1}{2}(106.5 + 73.2)\text{ kPa} * (0.2 - 0.5)\text{ m}^3$$

$$\boxed{W_{13} = -26.9\text{ kJ}}$$

$W < 0$ work done on the gas

Given

A gas inside a closed piston-cylinder device undergoing three processes

Find

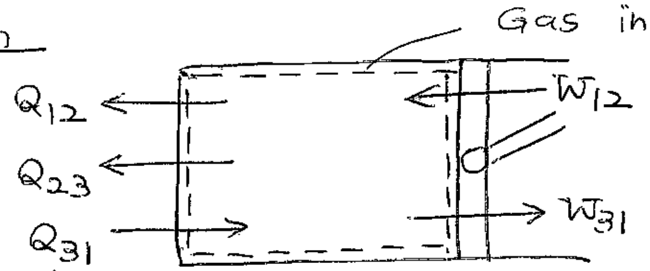
(a) P-V diagram

(b) Work (kJ) for each process

(c) Heat transfer (kJ) for each process

System

Gas inside the cylinder is the system



Assumptions

- Closed system (m = constant)
- Quasi-equilibrium process
- ~~Neglect friction between piston and cylinder wall~~
- Ignore KE and PE change

Basic Equations

$$Q - W = \Delta E = \Delta U + \underbrace{\cancel{\Delta KE}}_{\text{no}} + \underbrace{\cancel{\Delta PE}}_{\text{no}}$$

$W \rightarrow (W_{boundary} + \cancel{W_{other}})$, $W_{other} = 0$

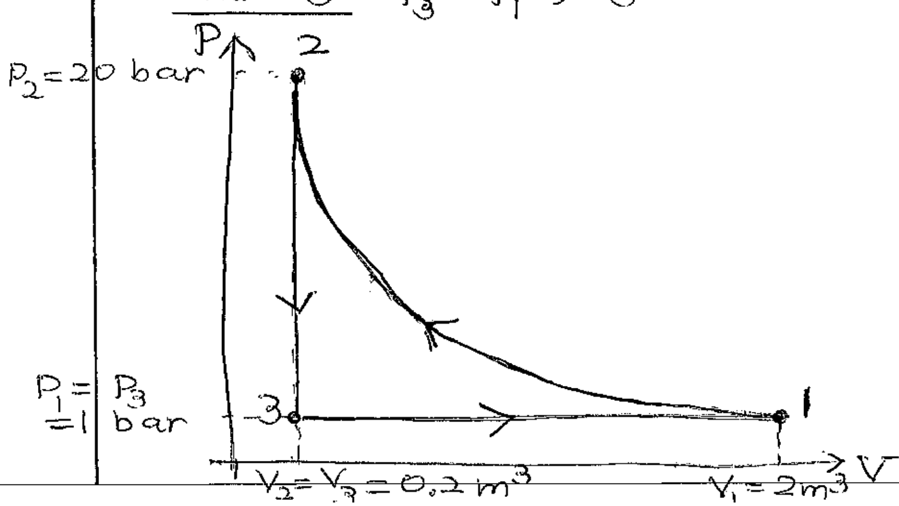
Solution

(a) State 1 $\quad P_1 = 1$ bar, $V_1 = 2\ m^3$

State 2 $\quad V_2 = 0.2\ m^3$, $P_2 V_2 = P_1 V_1$

$$\Rightarrow P_2 = 1 \text{ bar} * \frac{2\ m^3}{0.2\ m^3} = 10 \text{ bar}$$

State 3 $\quad P_3 = P_1$, $V_3 = V_2$



(b) Boundary work for each process:

$$W_{12} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{\text{constant}}{V}\,dV = \text{constant} \ln\frac{V_2}{V_1}$$

$$\text{constant} = P_1 V_1 = P_2 V_2 = (1\times 100)\,\text{kPa} * (2\,\text{m}^3) = 200\cdot\text{kJ}$$

$$W_{12} = 200\,\text{kJ} \ln\frac{0.2\,\text{m}^3}{2.0\,\text{m}^3} \Rightarrow \boxed{W_{12} = -460.5\,\text{kJ}}$$

$W<0$ work done on the gas

$$W_{23} = \int_{V_2}^{V_3} P\,\cancel{dV}^{\,0} \Rightarrow \boxed{W_{23} = 0}$$

$$W_{31} = \int_{V_3}^{V_1} P\,dV = (P_3 = P_1)(V_1 - V_3) = (1\times 100)\,\text{kPa} * (2-0.2)\,\text{m}^3$$

$$\Rightarrow \boxed{W_{31} = +180\,\text{kJ}}$$

$W>0$ work done by the gas

(c) Considering energy balance: $Q = W + \Delta U$

$$Q_{12} = W_{12} + \cancel{(U_2 - U_1)}^{\,0} \Rightarrow \boxed{Q_{12} = -460.5\,\text{kJ}}$$

$Q<0$ heat transfer out of the gas

$$Q_{23} = \cancel{W_{23}}^{\,0} + (U_3 - U_2) = (200 - 500)\,\text{kJ}$$

$$\Rightarrow \boxed{Q_{23} = -300\,\text{kJ}}$$

$Q<0$ heat transfer out of the gas

$$Q_{31} = W_{31} + (U_1 - U_3) = +180\,\text{kJ} + (500 - 200)\,\text{kJ}$$

$$\Rightarrow \boxed{Q_{31} = +480\,\text{kJ}}$$

$Q>0$ heat transfer into the gas

<u>Note</u>

$$W_{net} = W_{12} + W_{23} + W_{31} = -280.5\,\text{kJ}$$

$$Q_{net} = Q_{12} + Q_{23} + Q_{31} = -280.5\,\text{kJ}$$

$$\Delta U_{net} = \Delta U_{12} + \Delta U_{23} + \Delta U_{31} = 0$$

$$Q_{net} - W_{net} = \cancel{\Delta U_{net}}^{\,0} \Rightarrow Q_{net} = W_{net}$$

This is a "cyclic" system