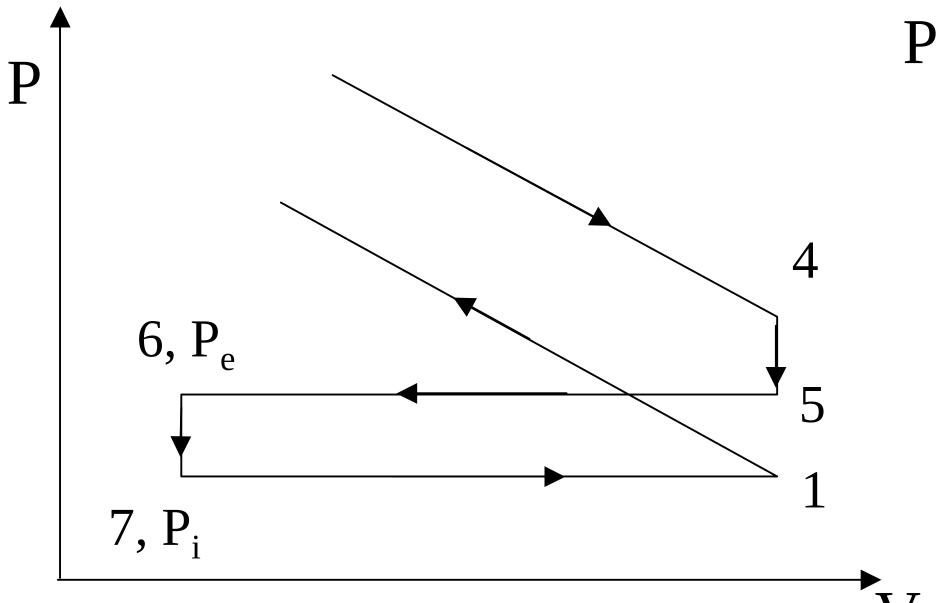
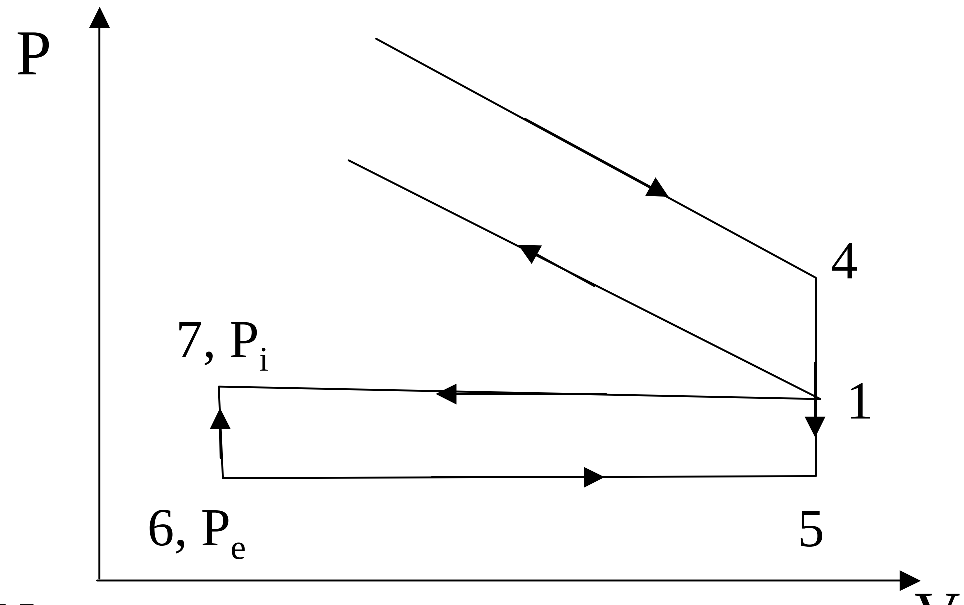
Intake Stroke

- Three possible scenarios during intake stroke
  - $P_i < P_e$: throttled; initially, the flow is going from the cylinder to the intake manifold (case 1 in the next page).
  - $P_i > P_e$: supercharged; initially, the flow is going from the intake to the cylinder. (might force some fresh charge through the exhaust valve due to the overlapping of the openings of the intake and exhaust valves (case 2).
  - $P_i = P_e$: unthrottled; the intake flow is driven only by the vacuum induced by the moving down motion of the piston (case 3)

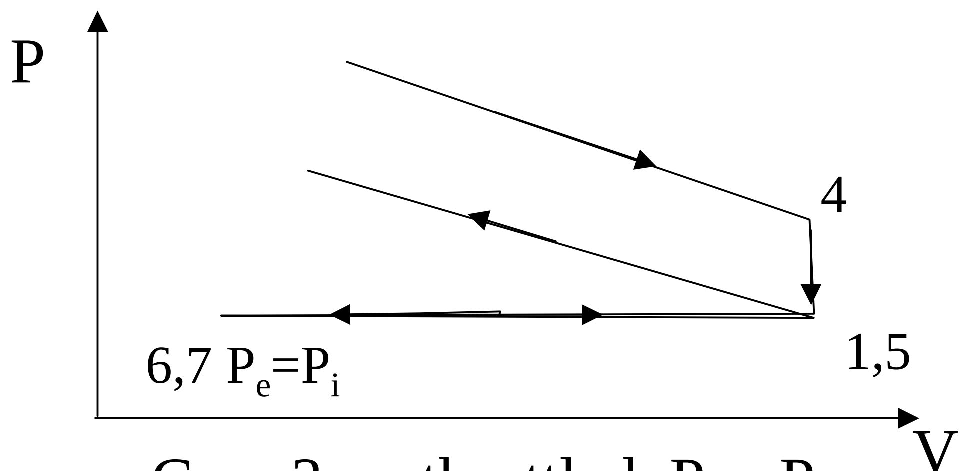
Intake Stroke Operating Modes



Case 1: throttled, $P_i < P_e$



Case 2: supercharged, $P_i > P_e$



Case 3: unthrottled, $P_i = P_e$

Temperature Change during Intake-1

- During the intake process, the temperature will change from the inlet temperature (T_i) to T_1, the cylinder temperature at the end of the intake stroke, due to the following factors:
  - Flow work
  - Heat transfer
  - Temperature of the exhaust gas (T_e)

- This temperature change can be determined using both the mass and energy conservation principles.
- It is also assumed that the cylinder pressure (P_1) is a constant and is the same as the inlet pressure (P_i). Note: P_e can be different from P_i as discussed earlier

Temperature Change during Intake-2

$\rightarrow$Mass conservation : $m_1 = m_i + m_6 = m_1 + m_1 f = m_1(1+f)$

where f is the residual gas fraction

$\rightarrow$ Unsteady energy equation (from state A to B) :

$$E_B - E_A = m_{in}(h + \frac{V^2}{2} + gz)_{in} - m_{out}(h + \frac{V^2}{2} + gz)_{out} + Q_{AB} - W_{AB}$$

B $\rightarrow$ 1 (before compression) and A $\rightarrow$ 6 (before intake)

$$m_1 u_1 \text{-} m_6 u_6 \text{-} m_i h_i = Q_{61} \text{-} W_{61}$$

$\rightarrow$ Ideal gas law : $P_e V_6 = m_6 R T_e$, $h = c_P T, c_p = \frac{\gamma R}{\gamma - 1}$

Show that $\Rightarrow T_1 = (1\text{-}f)T_i + fT_e\left[1 - \left(1 - \frac{P_i}{P_e}\right)\left(\frac{\gamma - 1}{\gamma}\right)\right]$

Gas Cycle Analysis

- Two more unknowns have been introduced in the cycle analysis: residual gas fraction (f) and temperature at the end of the intake stroke (T_1).
- These two unknowns are governed by two additional equations obtained earlier

$$\text{Intake stroke: } T_1 = (1-f)T_i + fT_e\left[1-\left(1-\frac{P_i}{P_e}\right)\left(\frac{\gamma-1}{\gamma}\right)\right]$$

$$\text{Exhaust stroke: } f = \frac{1}{r}\left(\frac{P_6}{P_4}\right)^{1/\gamma}$$

- They can not be solved independently from the other gas cycle equations since they are all inter-related.

Complete Cycle Analysis

1-2: isentropic compression: $P_2 = P_1 \left(V_1 \big/ V_2 \right)^{\gamma} = P_1 r^{\gamma}, T_2 = T_1 r^{\gamma - 1}$

2-3: constant volume heat addition: $T_3 = T_2 + \dfrac{q_{in}(1 - f)}{c_v},$

3-4: isentropic compression: $P_4 = P_3 (1/r)^{\gamma}, T_4 = T_3 (1/r)^{\gamma-1}$

4-5: isentropic blowdown (a model discussed earlier):

$T_5 = T_4 (P_4 / P_e)^{(1-\gamma)/\gamma}, P_5 = P_e$

5-6: adiabatic exhaust stroke: $T_e = T_5,\ P_6 = P_5 = P_e$

$f = (1/r)(P_6 / P_4)^{(1/\gamma)}$

6-1: intake stroke: $P_1 = P_i$

$$T_1 = (1 - f)T_i + fT_e \left[1 - \left(1 - \frac{P_i}{P_e} \right) \left(\frac{\gamma - 1}{\gamma} \right) \right]$$