Figure 1-8
Sequence of events in four-stroke spark-ignition engine operating cycle. Cylinder pressure $p$ (solid line, firing cycle; dashed line, motored cycle), cylinder volume $V/V_{\text{max}}$, and mass fraction burned $x_b$ are plotted against crank angle.
Pressure-volume diagram

Optimal spark timing is a function of operating condition

Fig. 5-1 Pressure-volume diagram of firing SI engine; compression ratio=8.4, 3500 rpm, intake pressure = 0.4 bar, Net IMEP = 2.9 bar

Ideal models of engine processes

Table 5.1

<table>
<thead>
<tr>
<th>Process</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression (1-2)</td>
<td>1. Adiabatic and reversible (hence isentropic)</td>
</tr>
<tr>
<td>Combustion (2-3)</td>
<td>1. Adiabatic</td>
</tr>
<tr>
<td></td>
<td>2. Combustion occurs at</td>
</tr>
<tr>
<td></td>
<td>(a) Constant volume</td>
</tr>
<tr>
<td></td>
<td>(b) Constant pressure</td>
</tr>
<tr>
<td></td>
<td>(c) Part at constant volume and part at constant pressure (called limited pressure)</td>
</tr>
<tr>
<td></td>
<td>3. Combustion is complete ($\eta_c = 1$)</td>
</tr>
<tr>
<td>Expansion (3-4)</td>
<td>1. Adiabatic and reversible (hence isentropic)</td>
</tr>
<tr>
<td>Exhaust (4-5-6)</td>
<td>1. Adiabatic</td>
</tr>
<tr>
<td>and intake (6-7-1)</td>
<td>2. Valve events occur at top- and bottom-center</td>
</tr>
<tr>
<td></td>
<td>3. No change in cylinder volume at pressure</td>
</tr>
<tr>
<td></td>
<td>differences across open valves drop to zero</td>
</tr>
<tr>
<td></td>
<td>4. Inlet and exhaust pressures constant</td>
</tr>
<tr>
<td></td>
<td>5. Velocity effects negligible</td>
</tr>
</tbody>
</table>
Different ideal cycles

Unthrottled constant volume combustion
Unthrottled limited-pressure combustion
Super-charged constant volume combustion

Unthrottled constant pressure combustion
Throttled constant volume combustion

Fig 5.2 Pressure-volume diagrams of ideal cycles

Ideal constant volume combustion cycle
Fuel conversion efficiency

Ideal efficiency

\[ \eta_{f,ig} = 1 - \frac{1}{r_c^{\gamma-1}} \]

\(\gamma = \text{specific heat ratio}\)

Fig. 5-5
Comparison of fuel conversion efficiency

Fig. 5-7 Fuel conversion efficiency as a function of compression ratio for constant-volume, constant-pressure, and limited pressure ideal gas cycles.

Factors affecting fuel conversion efficiency

These ideal engine cycle analysis results show that expansion ratio \( r_c \) and gas composition (through \( \gamma \) the ratio of specific heats) both affect the cycle's fuel conversion efficiency because:

1. The expansion ratio (which may or may not equal to the compression ratio) determines how much work is extracted over the expansion stroke.
2. The higher the value of \( \gamma \) the more the temperature falls during expansion, the larger the energy change and hence the larger the expansion stroke work.
3. The compression stroke work is of order one-sixth of the expansion stroke work so expansion stroke work effects dominate.
**Miller cycle**

- Late intake valve closing
  - Effective compression ratio is less than expansion ratio
- Advantages
  - Lower compression temperature
    - Better knock tolerance
    - Lower NOx emission
- Drawback
  - Reduced trapped charge mass: loss in max power
  - Compensated for by turbo-charging or hybrid operation

**Effects of compression ratio**

- Theoretical efficiency $\eta_f$ increases with CR
- SI engine CR limited by knocking to 12 (13 with direct injection)
- Practical $\eta_f$ values decreases at high CR
  - Heat transfer effect
  - Crevice effect
  - Dissociation effect
  - Friction
- Other considerations for diesel engines
  - Peak pressure
  - NOx emissions
  - Startability
Practical diesel engines have CR between 14 and 22
Effect of compression ratio on fuel conversion efficiency

FIGURE 15-14 Relative brake fuel conversion efficiency improvement with increasing compression ratio of spark-ignition engines of different displaced volume per cylinder at part throttle (except top curve at WOT). RL road load. CN, TO.