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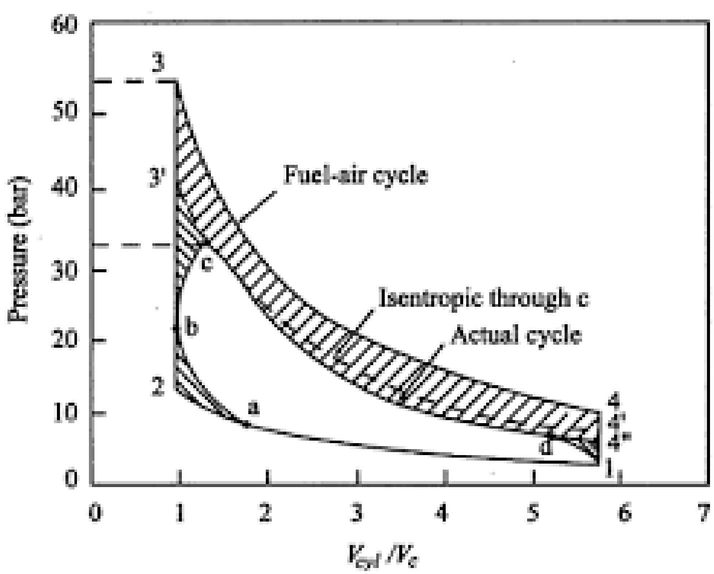
Internal Combustion Engines ENME 535

Department of Mechanical and Mechatronics Engineering

Dr. Mohammad Karaeen

Chapter 2: Air standard Cycles



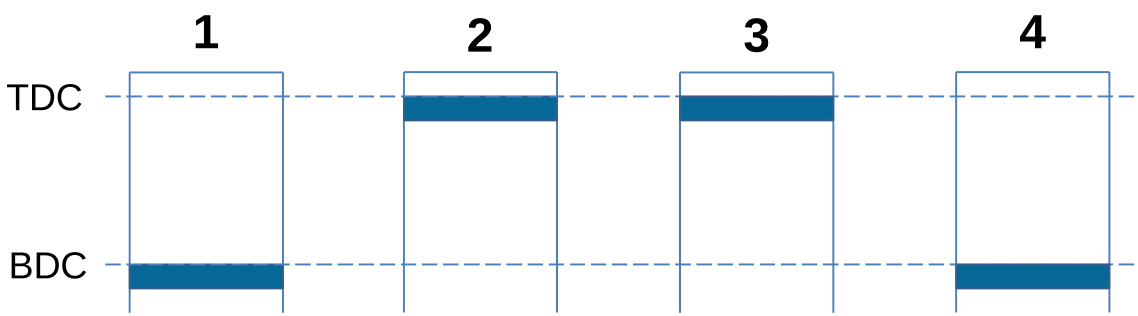
Internal Combustion Engine models can be approximated to one of the following:-

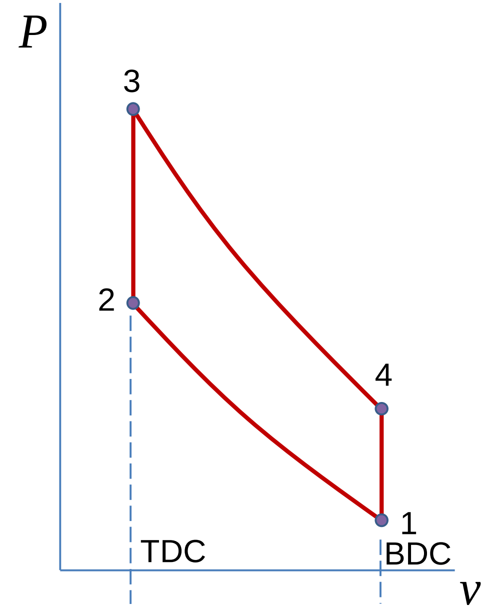
- The Otto Cycle.
- The Diesel Cycle.
- The Dual Cycles.
- The Actual Cycle

Air Standard Analysis and assumptions

- The working fluid is a fixed mass of air treated as an ideal gas
- No intake or exhaust
- The combustion process is replaced with a heat transfer from a high-temperature source
- The exhaust process is replaced with a heat transfer to a low-temperature sink
- All processes are internally reversible
- Heat capacity of the air is assumed to be constant at the ambient temperature

Air Standard Otto Cycle





- **1-2** Isentropic compression from BDC to TDC

$$W_{12} = m\left(u_2 - u_1\right)$$

- **2-3** Isochoric heat input (combustion)

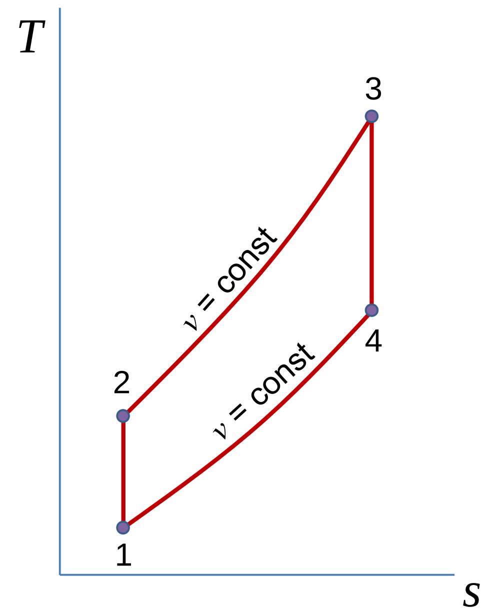
$$Q_{23} = m\left(u_3 - u_2\right)$$

- **3-4** Isentropic expansion (power stroke)

$$W_{34} = m\left(u_3 - u_4\right)$$

- **4-1** Isochoric heat rejection (exhaust)

$$Q_{41} = m\left(u_4 - u_1\right)$$



Air Standard Otto Cycle

Compression Ratio (*CR* or r_v)

$$CR = \frac{v_1}{v_2} = \frac{v_4}{v_3}$$

Thermal Efficiency

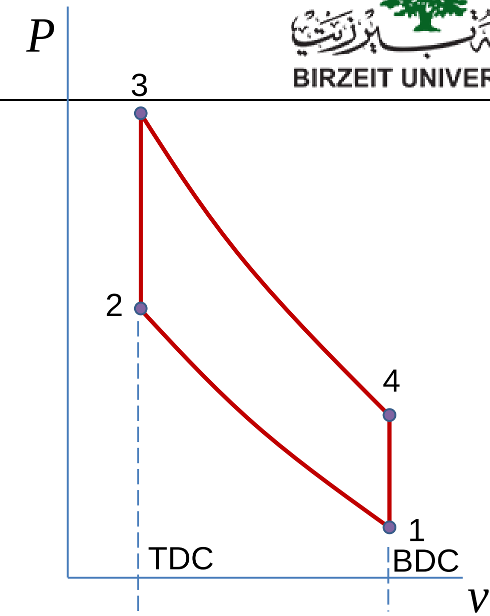
$$\eta_{th,\text{ASC}} = \frac{W_{net}}{Q_{in}} = \frac{W_{34} - W_{12}}{Q_{23}} = 1 - \frac{u_4 - u_1}{u_3 - u_2}$$

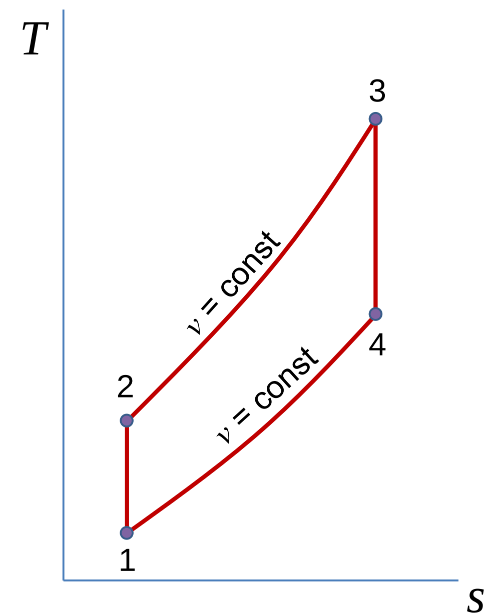
$$= 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2)}$$

but $\frac{T_2}{T_1} = (\frac{v_1}{v_2})^{k-1} = r_v{}^{k-1} = (\frac{v_4}{v_3})^{k-1} = \frac{T_3}{T_4}$

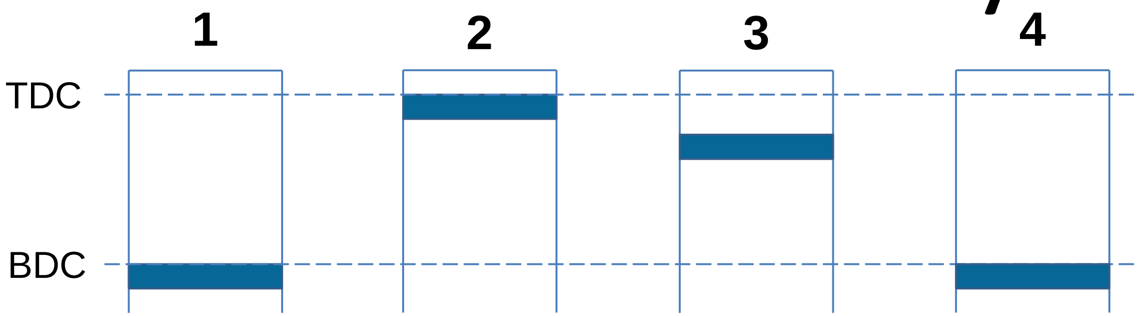
$$\therefore \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

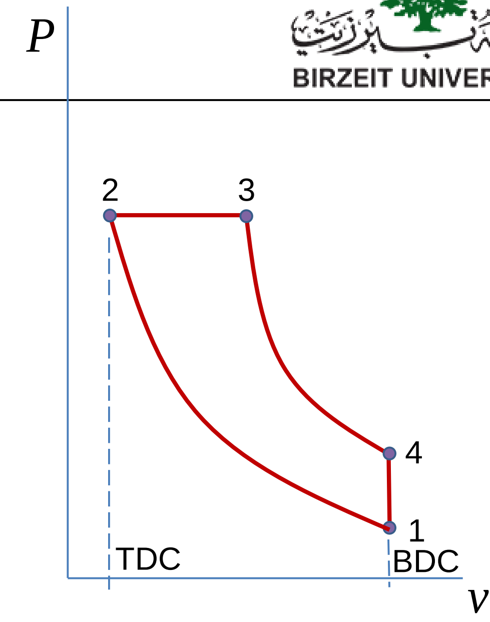
$$\eta_{th} = 1 - \frac{1}{[\![r_v^{k-1}]\!]}$$





Air Standard Diesel Cycle





- **1-2** Isentropic compression from BDC to TDC

$$W_{12} = m\left(u_2 - u_1\right)$$

- **2-3** Isobaric heat input (combustion)

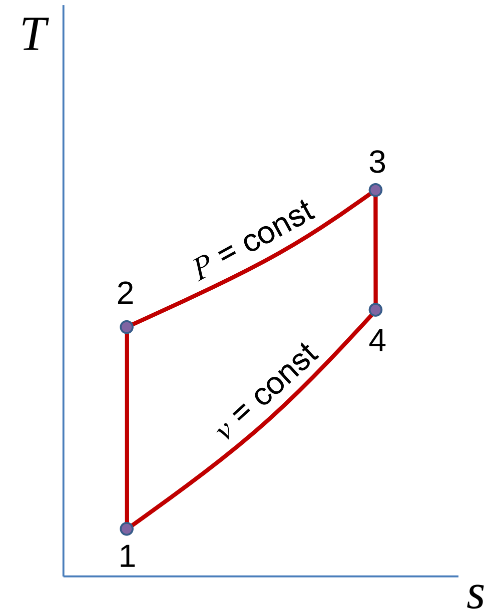
$$Q_{23} - W_{23} = m\left(u_3 - u_2\right)$$

- **3-4** Isentropic expansion (power stroke)

$$W_{34} = m\left(u_3 - u_4\right)$$

- **4-1** Isochoric heat rejection (exhaust)

$$Q_{41} = m\left(u_4 - u_1\right)$$



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Air Standard Diesel Cycle

Compression Ratio

$$r_v=\frac{v_1}{v_2}$$

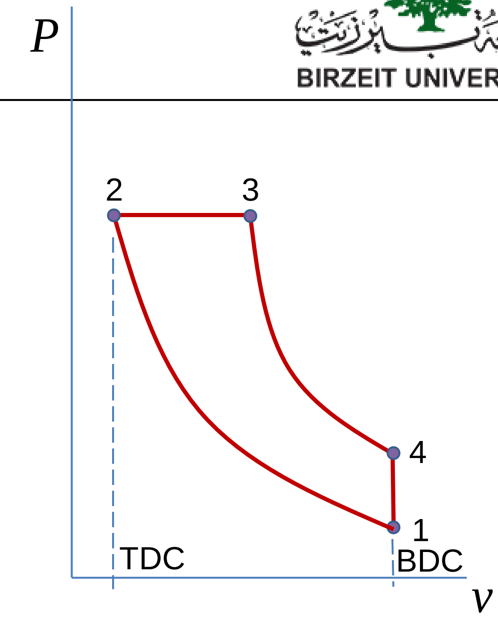
Cutoff Ratio

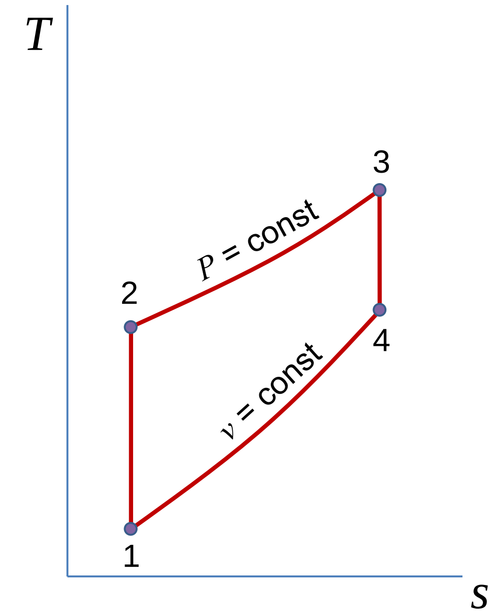
$$x=\frac{v_3}{v_2}$$

Thermal Efficiency

$$\eta_{th,\mathrm{ASC}}=\frac{W_{net}}{Q_{in}}=\frac{W_{23}+W_{34}-W_{12}}{Q_{23}}=1-\frac{u_4-u_1}{h_3-h_2}$$

$$\eta_{th}=1-\frac{c_v(T_4-T_1)}{c_p(T_3-T_2)}=1-\frac{(T_4-T_1)}{k(T_3-T_2)}$$





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Comparison Between Otto and Diesel Cycles

Otto	Diesel
1- Depends on Compression Ratio (CR : r_v)	1-Depends on both r_v and X
2- Efficiency is constant with variable load	2- Efficiency is variable with X
3- Followed by high speeds engines	3- Followed by slow speed engines.
4-Maximum pressure is higher	4- Maximum pressure is lower

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Air Standard Dual Cycle

$$\eta_{th} = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

Heat added and rejected are given by:

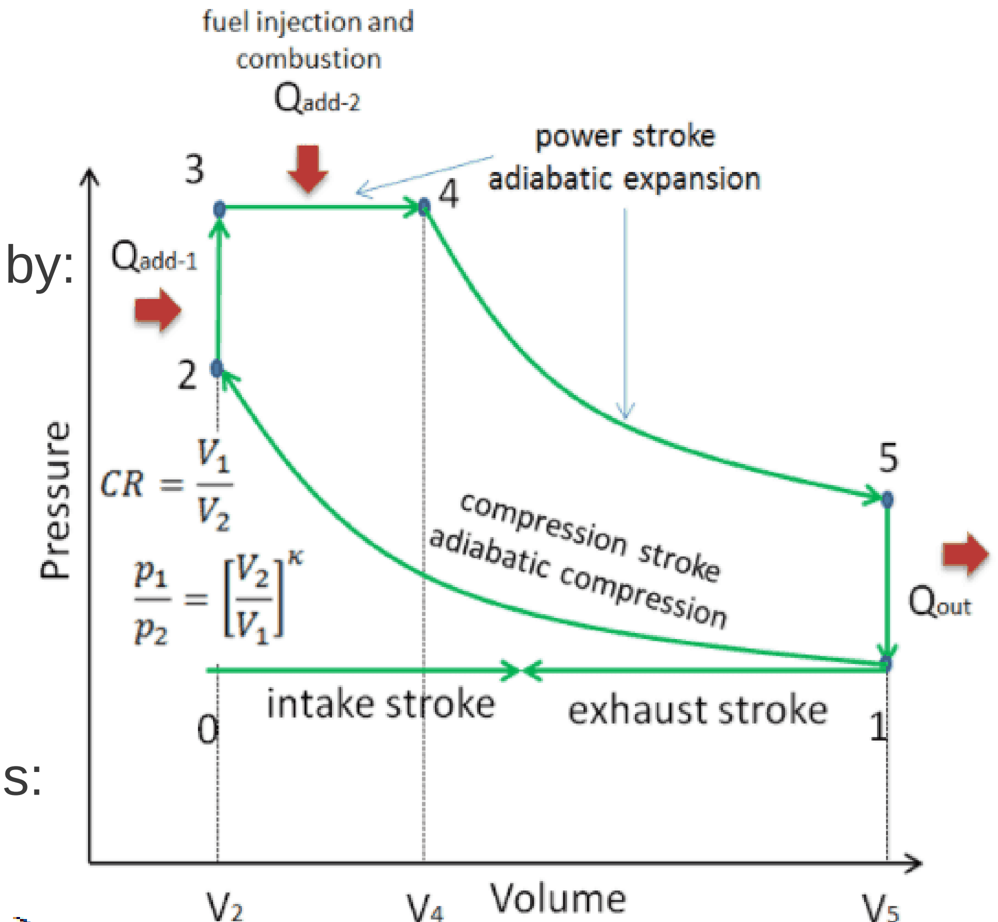
$Q_{add-1} = mc_v\,(T_3 - T_2)$

$Q_{add-2} = mc_p\,(T_4 - T_3)$

$Q_{out} = mc_v\,(T_5 - T_1)$

Thermal efficiency for a dual cycle is:

$$\eta_{th} = 1 - \frac{c_v(T_5 - T_1)}{c_v(T_3 - T_2) + c_p(T_4 - T_3)}$$



The actual cycle

The actual cycle experienced by internal combustion engines is an open cycle with changing composition, actual cycle efficiency is much lower than the air standard efficiency due to various losses occurring in the actual engine. These losses are as follows:

1- Losses due to variation of specific heats with temperature.

2- Losses due to dissociation

3- time losses: In theoretical cycles the burning is assumed to be instantaneous. Whereas, in actual cycle, burning is completed in a definite interval of time. The effect of this time is that the maximum pressure will not be produced when the volume is minimum; but sometime after T.D.C., causes a reduction in the work produced.