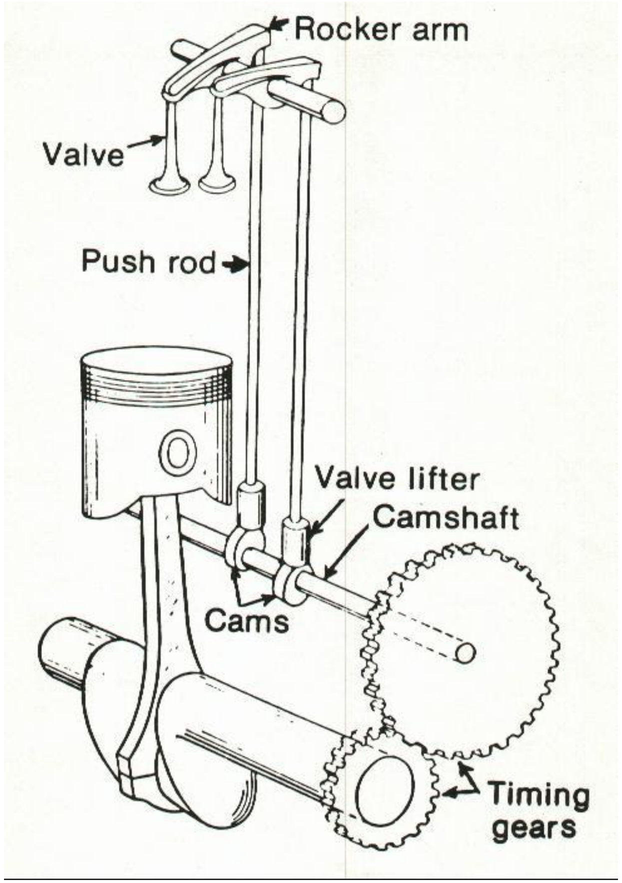
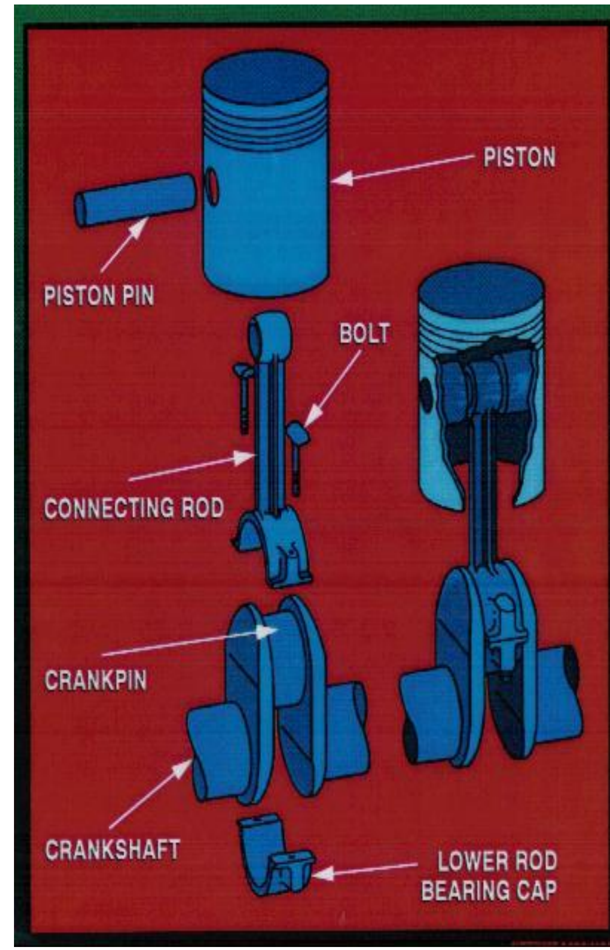
# Moving Components of I C Engine

- Valves
  - Intake: open to admit air to cylinder (with fuel in Otto cycle)
  - Exhaust: open to allow gases to be rejected
- Camshaft & Cams
  - Used to time the addition of intake and exhaust valves
  - Operates valves via pushrods & rocker arms



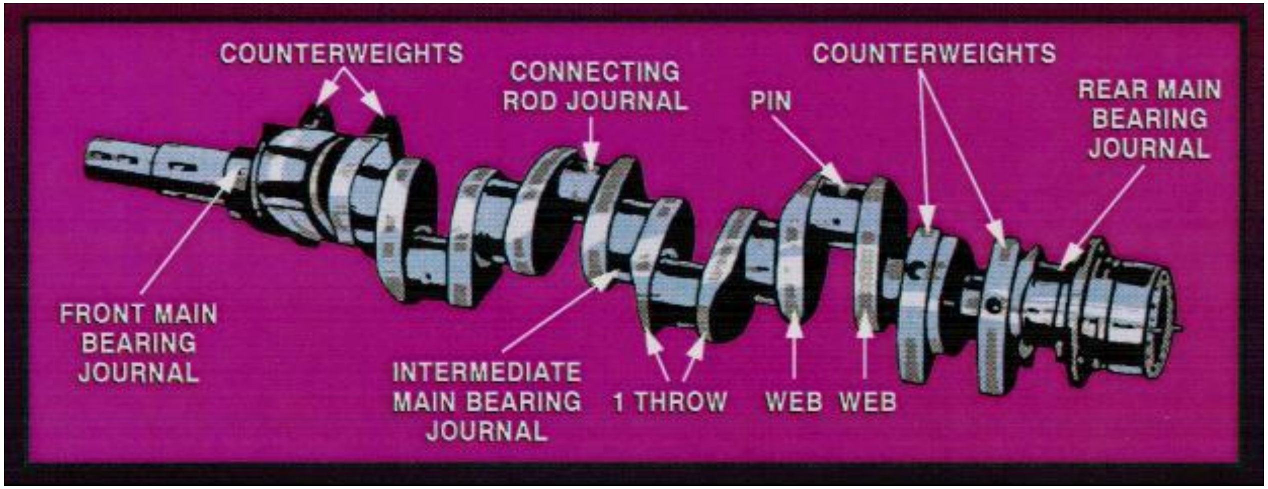
# Moving Components

- Piston
  - Acted on by combustion gases
  - Lightweight but strong/durable
- Piston Rings
  - Transfer heat from piston to cylinder
  - Seal cylinder & distribute lube oil
- Piston Pin
  - Pivot point connecting piston to connecting rod
- Connecting Rod
  - Connects piston & crankshaft
  - reciprocating $\rightarrow$ rotating motion

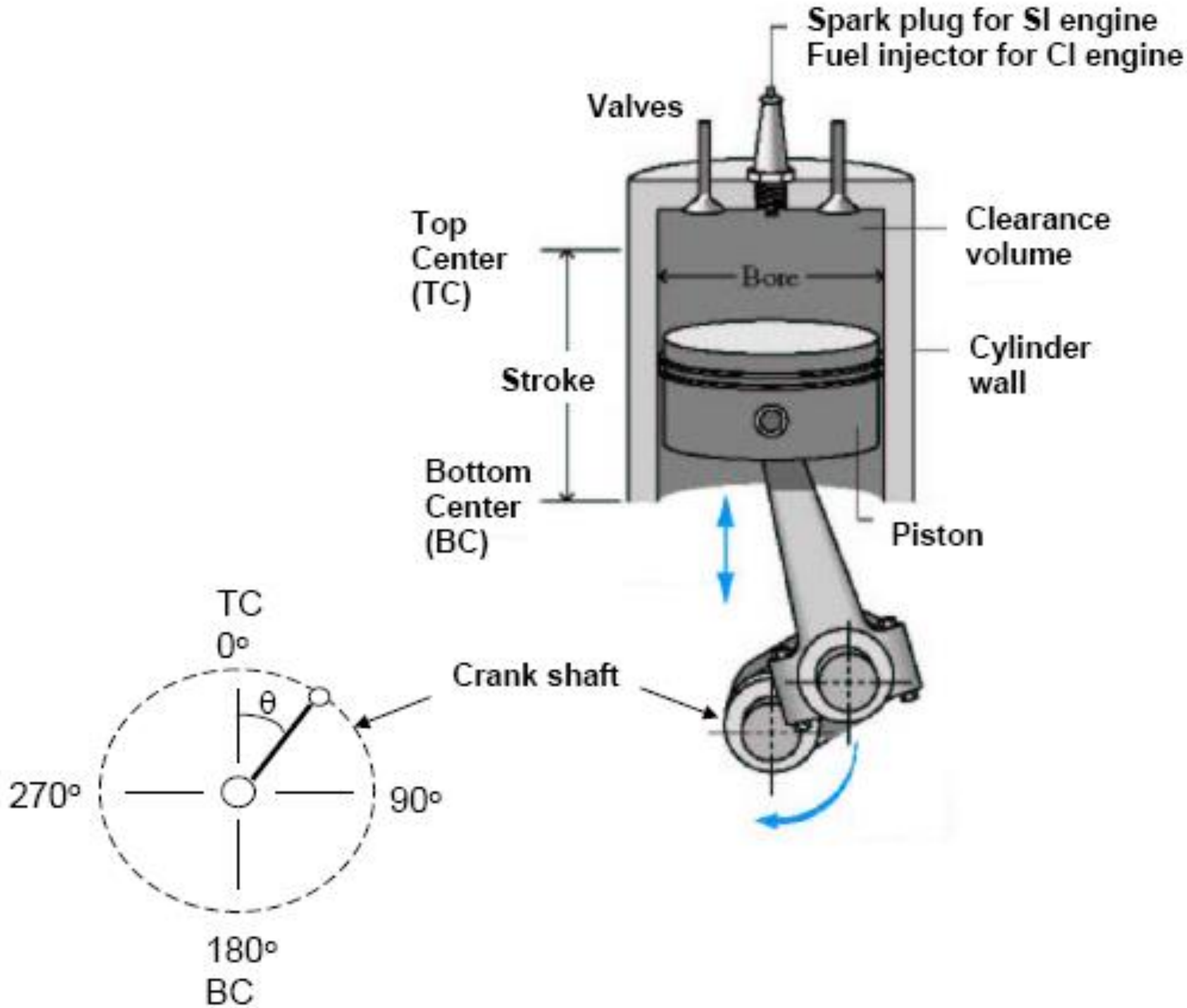


# Moving Components

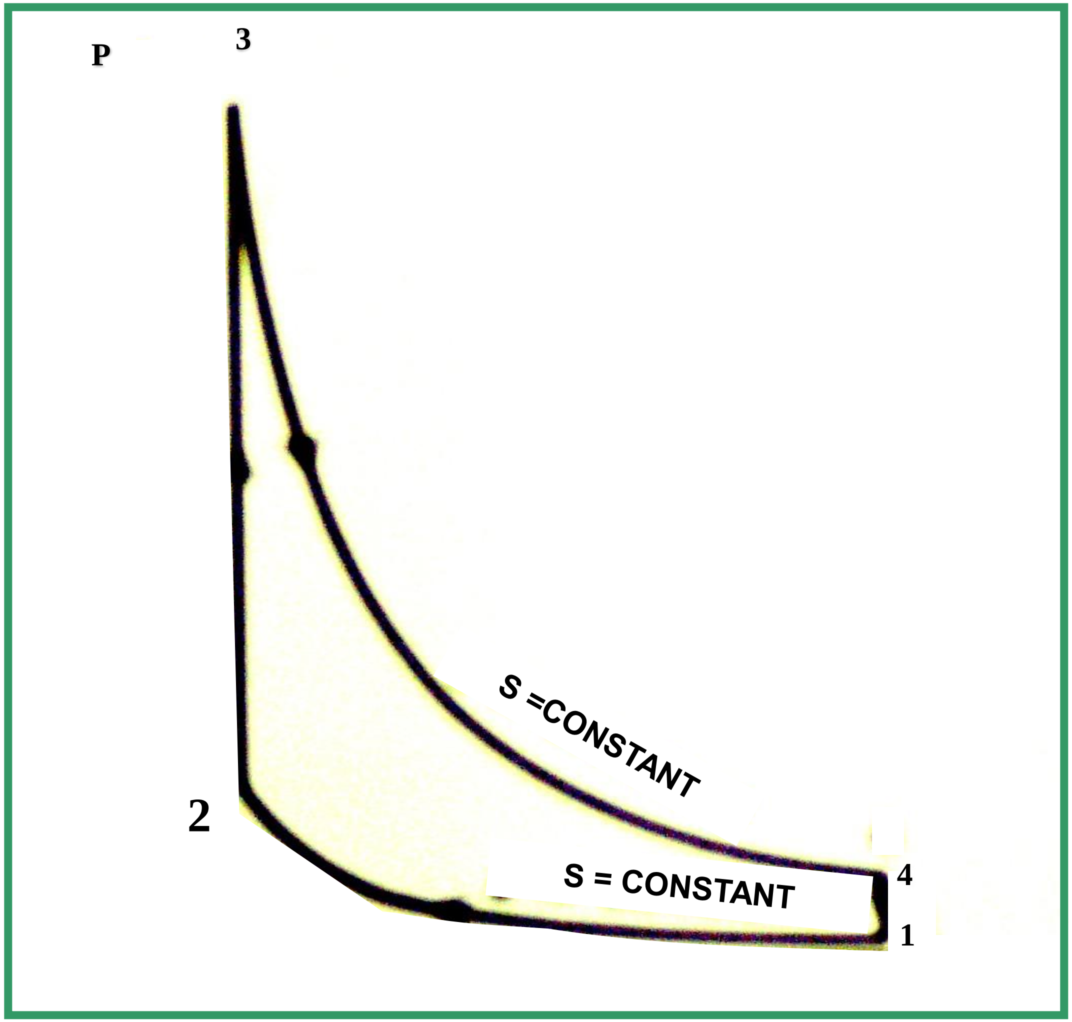
- Crankshaft
  - Combines work done by each piston
  - Drives camshafts, generator, pumps, etc.
- Flywheel
  - Absorbs and releases kinetic energy of piston strokes -> smoothes rotation of crankshaft



# Otto (SI Engine) Operating Cycle



# Air Standard Cycles




**Otto Cycle: An ideal cycle that approximates a spark-ignition internal-combustion engine.**

**Process:** **1-2** **Isentropic Compression of Air**

**2-3** **Heat Addition at Constant Volume**

**3-4** **Isentropic Expansion**

**4-1** **Rejection of Heat from the Working Fluid at Constant Volume**

**Compression Ratio =** $$r_v = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

**Assuming constant specific heats of air:**

$$\eta_{th} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

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

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

**Since** $\frac{V_1}{V_2} = \frac{V_4}{V_3}$, **processes are isentropic (1-2 and 3-4)**

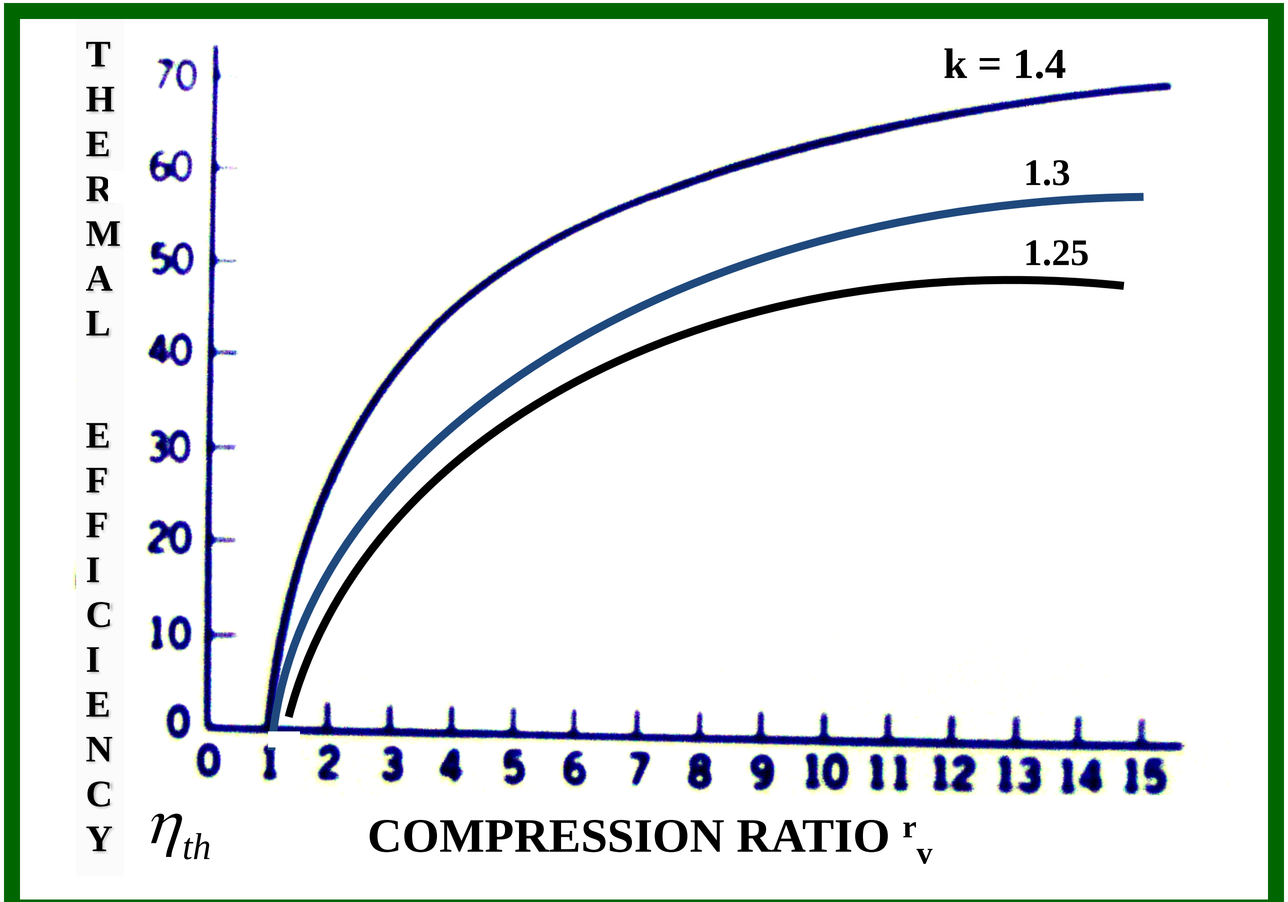
$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} = \left(\frac{V_4}{V_3}\right)^{k-1} = \frac{T_3}{T_4}$$

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

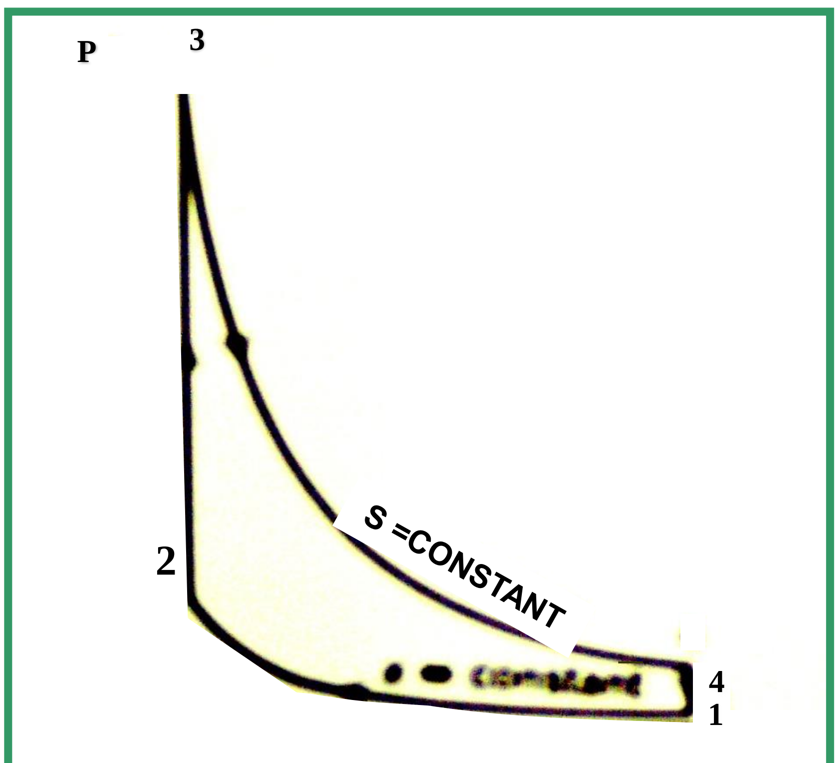
$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - r_v^{(1-\kappa)} = 1 - \frac{1}{r_v^{\kappa-1}}$$

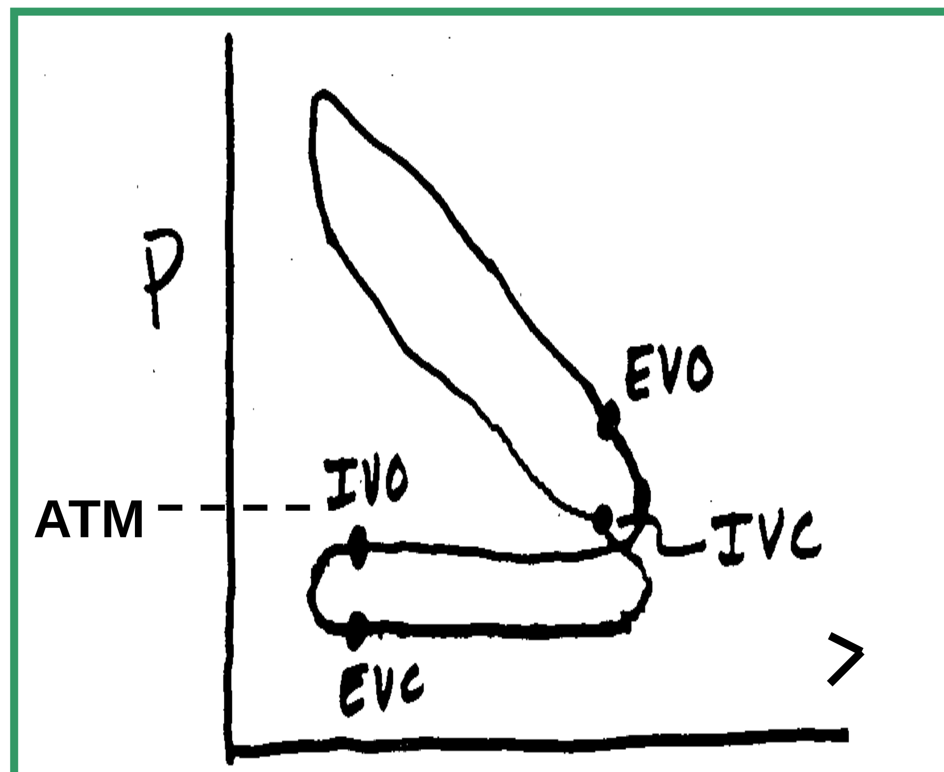
**Note: Air standard Otto cycle is only a function of compression ratio.**

# Thermal Efficiency of the Otto Cycle as a Function of Compression Ratio



# Thermal efficiency of an air-standard Otto Cycle as a function of compression ratio. Comparison of air-standard cycle with an actual cycle



# Primary Physical Differences

# Air Standard Cycle vs. Actual Cycle

(Actual Cycle is Typical S-I 4-Stroke)

| Process | Air Standard | Actual Cycle |
| --- | --- | --- |
| 1-2 | Isentropic Compression of Air | Some heat-transfer, but in a good engine, peak pressure during motoring is nearly equal to the pressure calculated with isentropic relationships. Intake valve closes. |
| 2-3 | Constant Volume Heat Addition | Heat addition takes place over an interval of time. Heat is lost to piston, cylinder walls and to cylinder head during this time. |
| 3-4 | Isentropic Expansion Combustion is Complete | Combustion continues into the expansion stroke. Heat transfer takes place and energy is lost to cylinder walls, head and piston. Piston ring blow-by occurs, as well as blowback. Exhaust valve opens and a blowdown process begins. |
| 4-1 | Reject of Heat from Working Fluid While Piston is at Rest | Piston completes a mechanical stroke to expel spent exhaust gases and an intake stroke to induct fresh charges – pumping work occurs. Wave dynamics from other cylinders may be present. |

# Gas Laws

With constant pressure $\frac{V_1}{V_2} = \frac{T_1}{T_2}$

With constant volume $\frac{P_1}{P_2} = \frac{T_1}{T_2}$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \cdots = \frac{PV}{T} = R$$

$$PV = MRT$$

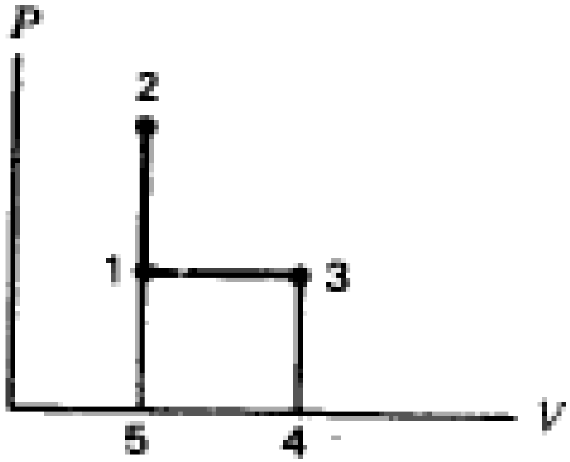
$M$ = the mass of gas considered
$P$ = the absolute pressure
$V$ = the volume of the mass $M$
$T$ = the absolute temperature

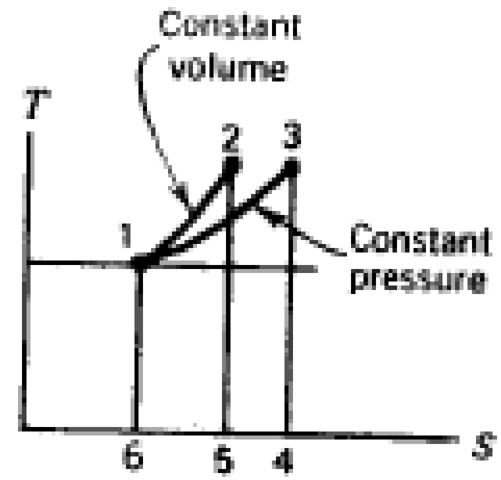
$$R = 8.314 \frac{\mathrm{J}}{\mathrm{g\ mole\ K}}$$

$$Q = Mc(T_2 - T_1) = (U_2 - U_1) + W$$

where
$Q$ = heat gained or rejected
$M$ = mass of the gas
$c$ = specific heat
$(U_2 - U_1)$ = change in internal energy
$W$ = work done

$c_v$ = specific heat at constant volume
$c_p$ = specific heat at constant pressure
$k = c_p/c_v$




**<u>Constant Volume Changes</u>**

General Equation is

$$C_v\,(T_2 - T_1) = U_2 - U_1$$

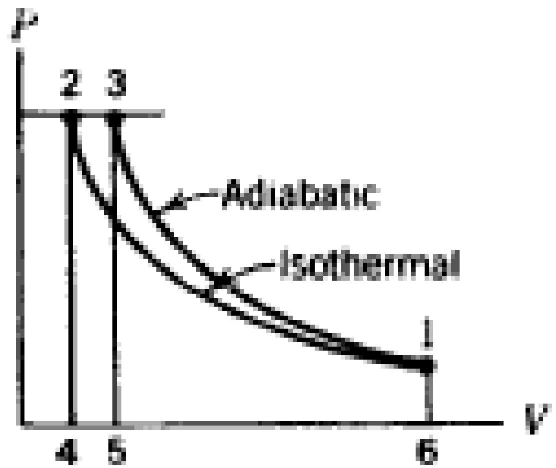
**<u>Constant Pressure Changes</u>**

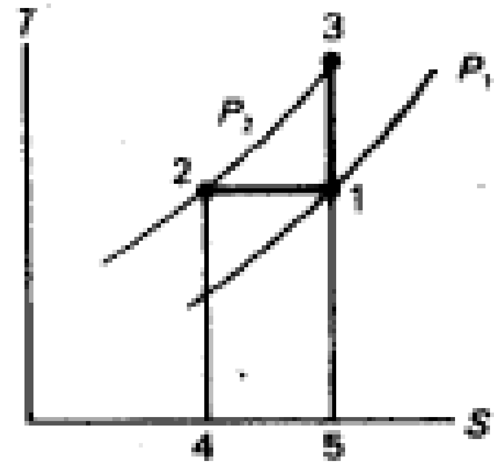
$C_p(T_3 - T_1) = C_v\,(T_3 - T_1) + P\,(V_3 - V_1)$,

But, $P_3V_3 = RT_3$, $P_1V_1 = RT_1$ and $P_1 = P_3$

So, $C_p(T_3 - T_1) = C_v\,(T_3 - T_1) + R(T_3 - T_1)$

Or, $C_p - C_v = R$




<u>Isothermal Changes</u>

PV = C (Constant ), Boyles' Law

The work done during any change in volume from $V_1$ to $V_2$ is

$$W = \int_{V_1}^{V_2} P\, dV$$

$$W = \int_{V_1}^{V_2} \frac{C}{V}\, dV = C \int_{V_1}^{V_2} \frac{dV}{V} = C[\log_e V]\Big|_{V_1}^{V_2}$$

$$W = C(\log_e V_2 - \log_e V_1)$$

Since the initial conditions are $PV = C = P_1V_1$, this value may be subs in equation 16 to obtain

$$W = P_1V_1(\log_e V_2 - \log_e V_1)$$

or

$$W = P_1V_1 \log_e \frac{V_2}{V_1}$$

For any mass of gas other than unity there may be substituted

$$P_1V_1 = MRT$$

and

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

**The work is**

$$W = MRT \log_e \frac{V_2}{V_1} = MRT \log_e \frac{P_1}{P_2}$$

Letting $r = V_1/V_2$ be the compression ratio or ratio of expansion, we h:

$$W = MRT \log_e \frac{1}{r}$$

# Adiabatic or constant Entropy Changes

$$0 = c_v(T_3 - T_1) + W$$
$$W = -c_v(T_3 - T_1)$$

unit mass

$$W = -c_v\left(\frac{P_3V_3}{R} - \frac{P_1V_1}{R}\right) = -\frac{1}{R}c_v(P_3V_3 - P_1V_1)$$

:

$$R = c_p - c_v$$

$$W = -\frac{c_v}{c_p - c_v}(P_3V_3 - P_1V_1)$$
$$W = \frac{P_3V_3 - P_1V_1}{1 - k} = \frac{P_1V_1 - P_3V_3}{k - 1}$$

unit mass of gas.
For $M$ mass units of gas,

$$W = \frac{MR(T_1 - T_3)}{k - 1}$$

# General or Polytropic Changes

$$W = \int P\,dV$$

$$P_1V_1^n = PV^n$$

$$P = P_1V_1^n \frac{1}{V^n}$$

Substituting,

$$W = P_1V_1^n \int_{V_1}^{V_2} \frac{dV}{V^n} = P_1V_1^n \int_{V_1}^{V_2} V^{-n}\,dV$$

$$= \frac{P_1V_1^n}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$= \frac{P_1V_1^nV_2^{1-n} - P_1V_1^nV_1^{1-n}}{1-n}$$

Substituting $P_1V_1^n = P_2V_2^n$,

$$W = \frac{P_2V_2^nV_2^{1-n} - P_1V_1^nV_1^{1-n}}{1-n} = \frac{P_2V_2 - P_1V_1}{1-n}$$

If $n = k$, then

$$W = \frac{P_2V_2 - P_1V_1}{1-k}$$

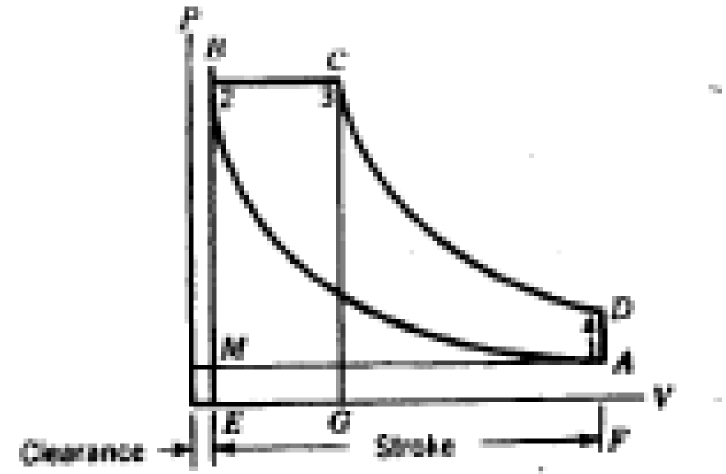
$$T_2 = T_1\left(\frac{V_2}{V_1}\right)^{1-k} = T_1\left(\frac{V_1}{V_2}\right)^{k-1} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$= T_1\left(\frac{P_2}{P_1}\right)^{1-(1/k)}$$

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{k} = P_1\left(\frac{T_2}{T_1}\right)^{k/(k-1)}$$

$$V_2 = V_1\left(\frac{P_1}{P_2}\right)^{1/k} = V_1\left(\frac{T_1}{T_2}\right)^{1/(k-1)}$$

# EFFICIENCY OF DIESEL CYCLE




$$Q_{in} = Mc_p(T_3 - T_2) \qquad Q_{out} = Mc_v(T_4 - T_1)$$

$$e = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$= 1 - \frac{Mc_v(T_4 - T_1)}{Mc_p(T_3 - T_2)} = 1 - \frac{(T_4 - T_1)}{k(T_3 - T_2)}$$

$$= 1 - \frac{T_1}{T_2}\left[\frac{\left(\frac{T_4}{T_1} - 1\right)}{k\left(\frac{T_3}{T_2} - 1\right)}\right]$$

$$T_3 = T_2 \frac{V_3}{V_2} \text{ at constant pressure}$$

$$T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{k-1} \text{ adiabatically}$$

$$T_4 = T_2 \frac{V_3}{V_2} \left(\frac{V_3}{V_4}\right)^{k-1} = T_2 \frac{(V_3/V_2)^k}{(V_4/V_2)^{k-1}}$$

Since the compression from 1 to 2 is adiabatic and $V_4 = V_1$, we have

$$T_2 = T_1 \left(\frac{V_4}{V_2}\right)^{k-1}$$

Solving for $T_1$ and then dividing $T_4$ by $T_1$ we obtain

$$\frac{T_4}{T_1} = \frac{(V_4/V_2)^{k-1}(V_3/V_2)^k}{(V_4/V_2)^{k-1}} = \left(\frac{V_3}{V_2}\right)^k$$

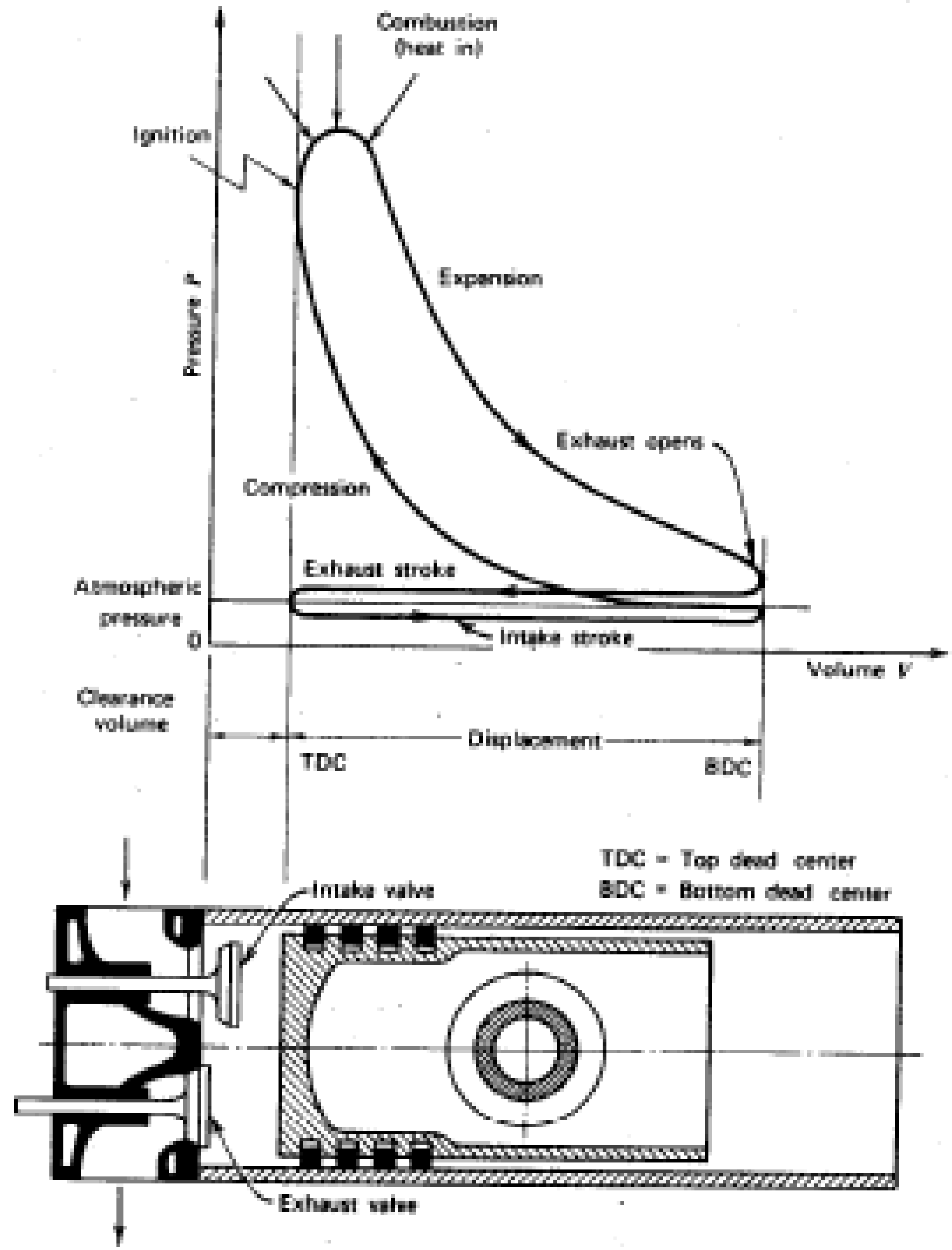
$$e = 1 - \frac{T_1[(V_3/V_2)^k - 1]}{kT_2[(V_3/V_2) - 1]}$$

$$T_1 = T_2\left(\frac{V_2}{V_1}\right)^{k-1}$$

$$e = 1 - \left\{\frac{(V_2/V_1)^{k-1}\,[(V_3/V_2)^k - 1]}{k[(V_3/V_2) - 1]}\right\}$$

$$= 1 - \frac{1}{(V_1/V_2)^{k-1}}\left[\frac{(V_3/V_2)^k - 1}{k[(V_3/V_2) - 1]}\right]$$

$$e = 1 - \frac{1}{r^{k-1}}\left[\frac{(V_3/V_2)^k - 1}{k[(V_3/V_2) - 1]}\right]$$



Combustion
(heat in)
Ignition
Pressure P
Expansion
Exhaust opens
Compression
Exhaust stroke
Atmospheric
pressure
0
Intake stroke
Volume V
Clearance
volume
Displacement
TDC
BDC
TDC = Top dead center
BDC = Bottom dead center
Intake valve
Exhaust valve