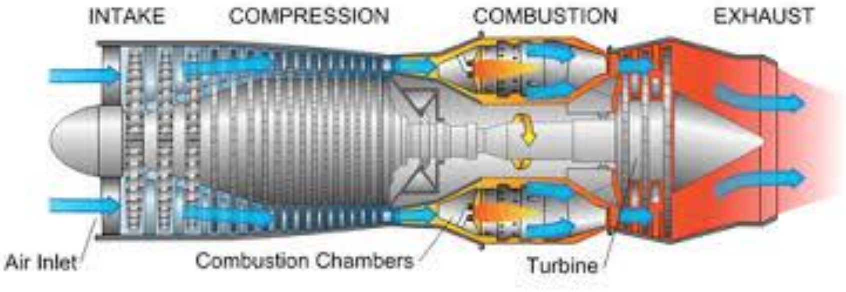
TIKRIT UNIVERSITY
COLLEGE OF ENGINEERING
MECHNICAL DEPARTMENT
INTERNAL COMBUSTION ENGINE



# Chapter 4

# Fuel-Air and Actual Cycles and their Analysis

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# Introduction

**The simple ideal air standard cycles overestimate the engine efficiency by a factor of about 2.**

**For $r = 8$** → **For example:** **Ideal cycle analysis $\eta_{th,Otto} = 56.5\ \%$, while the actual operation of SI engine $\eta_{th,i} = 28\ \%$.**

**The probable reasons for deviation:**

- **Simplified assumptions.**
- **Incomplete combustion of fuels.**
- **Progressive burning of fuel.**
- **Valve operation.**

**FUEL – AIR CYCLE is the theoretical cycle based on the actual properties of the cylinder contents. The fuel – air cycle take into consideration the following:**

1) **The actual composition of the cylinder contents (mixture of air, fuel vapour and residual gases from previous cycle).**

2) **The variation in the specific heat of the gases in the cylinder.**

3) **The dissociation effect.**

Dissociation of CO2 (at ≈1000 °C):

$$CO_2 \rightleftarrows 2CO + O_2$$

Dissociation of H2O (at ≈1000 °C):

$$2H_2 + O_2 \rightleftarrows 2H_2O$$

4) **The variation in the number of moles present in the cylinder as the pressure and temperature change.**

$$pV = N\bar{R}T$$

**Assumptions in Fuel-air Cycle** Following assumptions are commonly made:

1) There is **no chemical change** in either fuel or air **prior to combustion**.

2) Just after combustion, charge is always **in chemical equilibrium**.

3) Cylinder walls are **adiabatic** (no heat transfer between gases and walls).

4) Compression and expansion processes are **frictionless**.

5) The velocities of gases are **negligibly small**.

6) Fuel is **vaporized and completely mixed** with air.

7) Combustion takes place **instantaneously** at **TDC** (at constant volume).

**Q: What is the significant of Fuel-Air cycles analysis, since it is still based on theoretical aspects?**

- Air-Standard cycles: effect of **compression ratio only** on engine performance.
- Even though the Fuel-Air cycles have the same theoretical base of the Air-Standard cycles, it **introduced another important parameter** for **real engine** operation which is the **AFR**.
- So, peak pressure and temperature estimated **close to** actual values.

# Considerations in Fuel-Air cycles

## 1. Composition of cylinder gases:

- Air-fuel ratio changes during engine operation.
- Change in fuel-air ratio affects the composition of gases after combustion such as CO2, CO, water vapour etc.

## 2. Variable specific heats:

- Specific heat generally increases with increase in temperature (except for mono-atomic gases).
- Over the temperature range generally observed for gases in a heat engines (300 to 2000K), specific heat follows nearly a linear relationship with temperature.

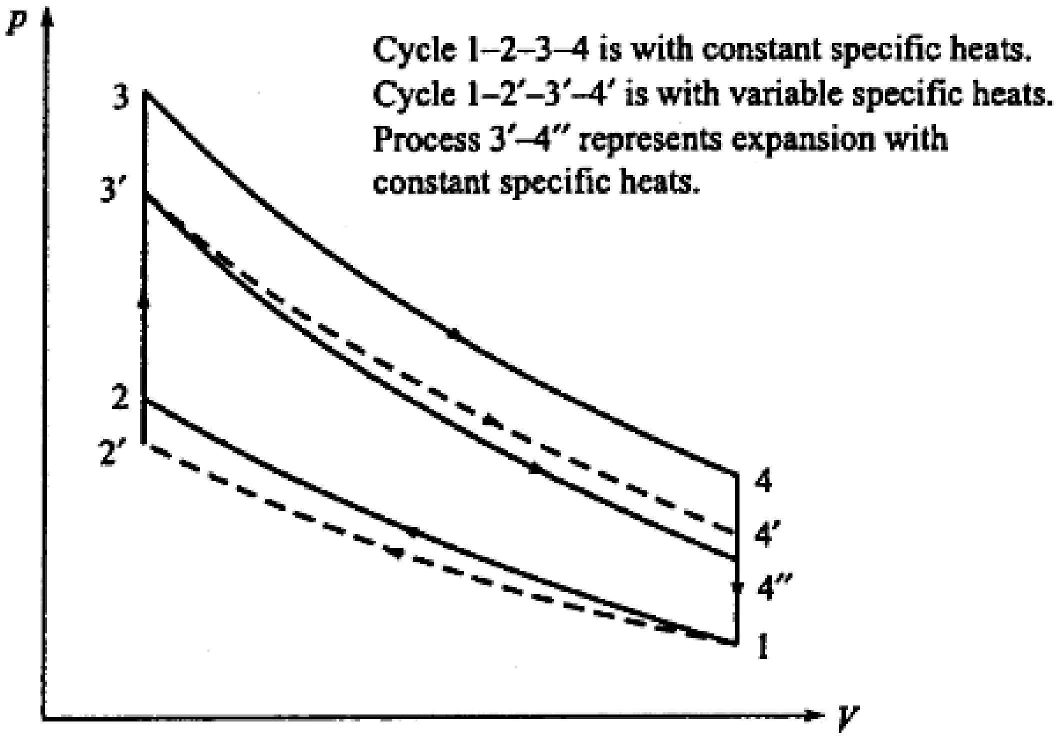
$$C_p = a_1 + a_2 \times T$$
$$C_v = b_1 + a_2 \times T$$

**Where $a_1$, $b_1$and $a_2$ are constants.**

- $C_p - C_v = R$, **where $R$ is gas constant and $k = \frac{C_p}{C_v}$.**
- **Thus $k$, decreases as temperature increases.**

- **Since $T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{k-1}$** , $T_2' < T_2$
- Also, $T_3' < T_3$, since, for given heat release, ΔT decreases as Cp increases.
- Overall effect: lower pressure and temperatures at points 2 and 3, thus less work output than the cycle with constant specific heat case.

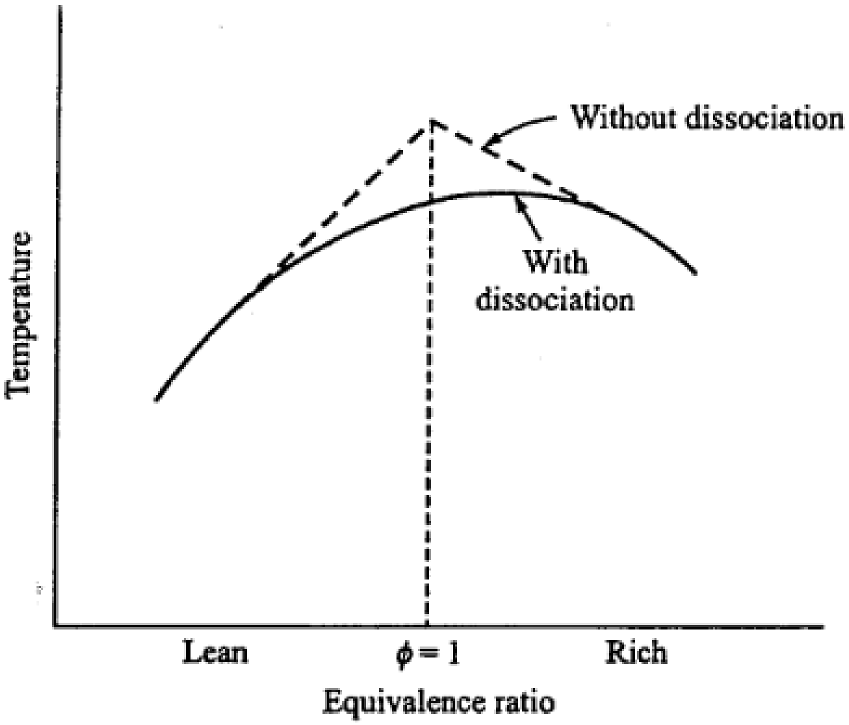
$T_4' > T_4''$ since specific heat decreases when temperature decreases.

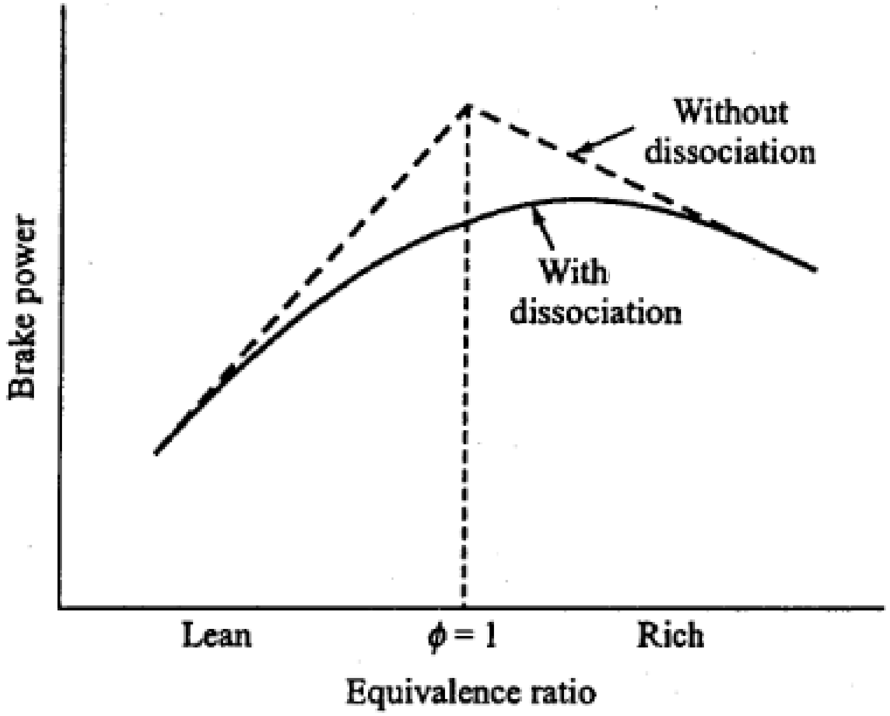


Cycle 1–2–3–4 is with constant specific heats.
Cycle 1–2′–3′–4′ is with variable specific heats.
Process 3′–4″ represents expansion with constant specific heats.

### 3. **Dissociation**: is the disintegration of combustion products at high temperatures.

- Heat is absorbed during dissociation and released when disintegration products recombine as temperature decreases.
- Overall effect: Heat absorption in combustion process and liberation in the expansion stroke. Dissociation limits mixture temperature after combustion.
- Dissociation is max for chemically correct mixtures, because of max heat generation.



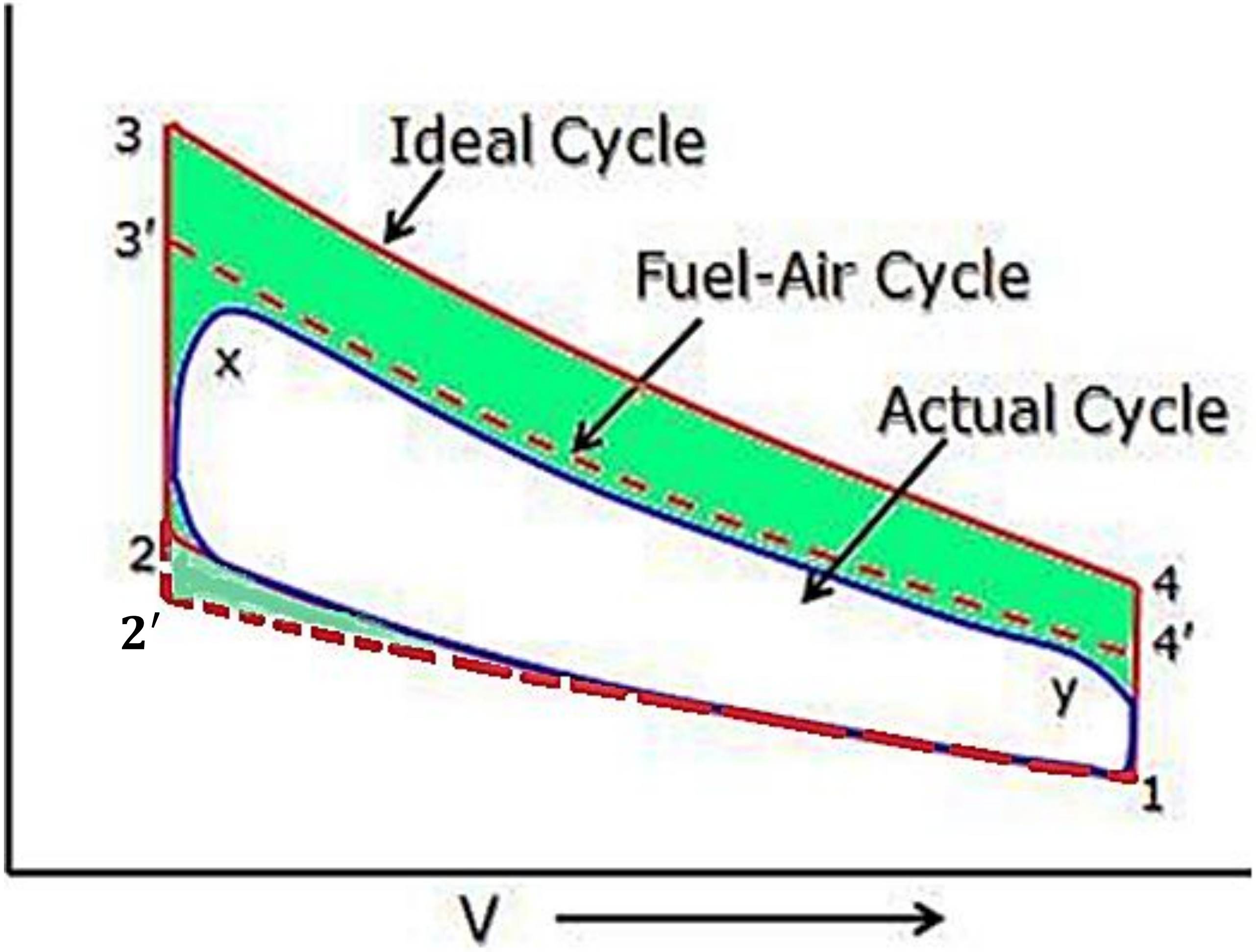


4. **Number of moles**: Number of moles of combustion products depends on air fuel ratio. Overall, it affect power output .

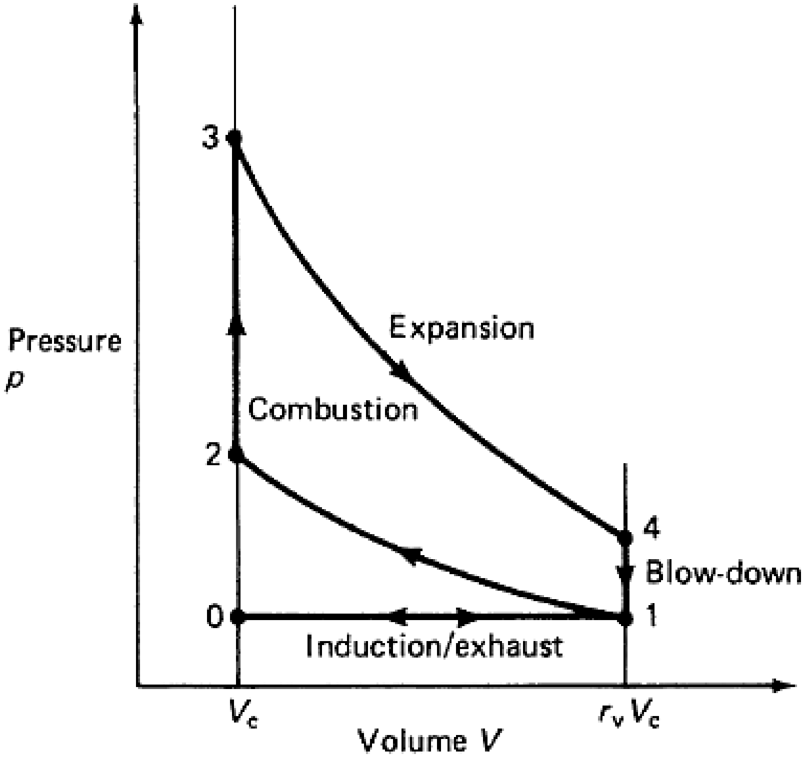
$$pV = N\overline{R}T$$

$C_3H_8 + 5O_2 \rightarrow 2CO + CO_2 + 4H_2O + O_2$

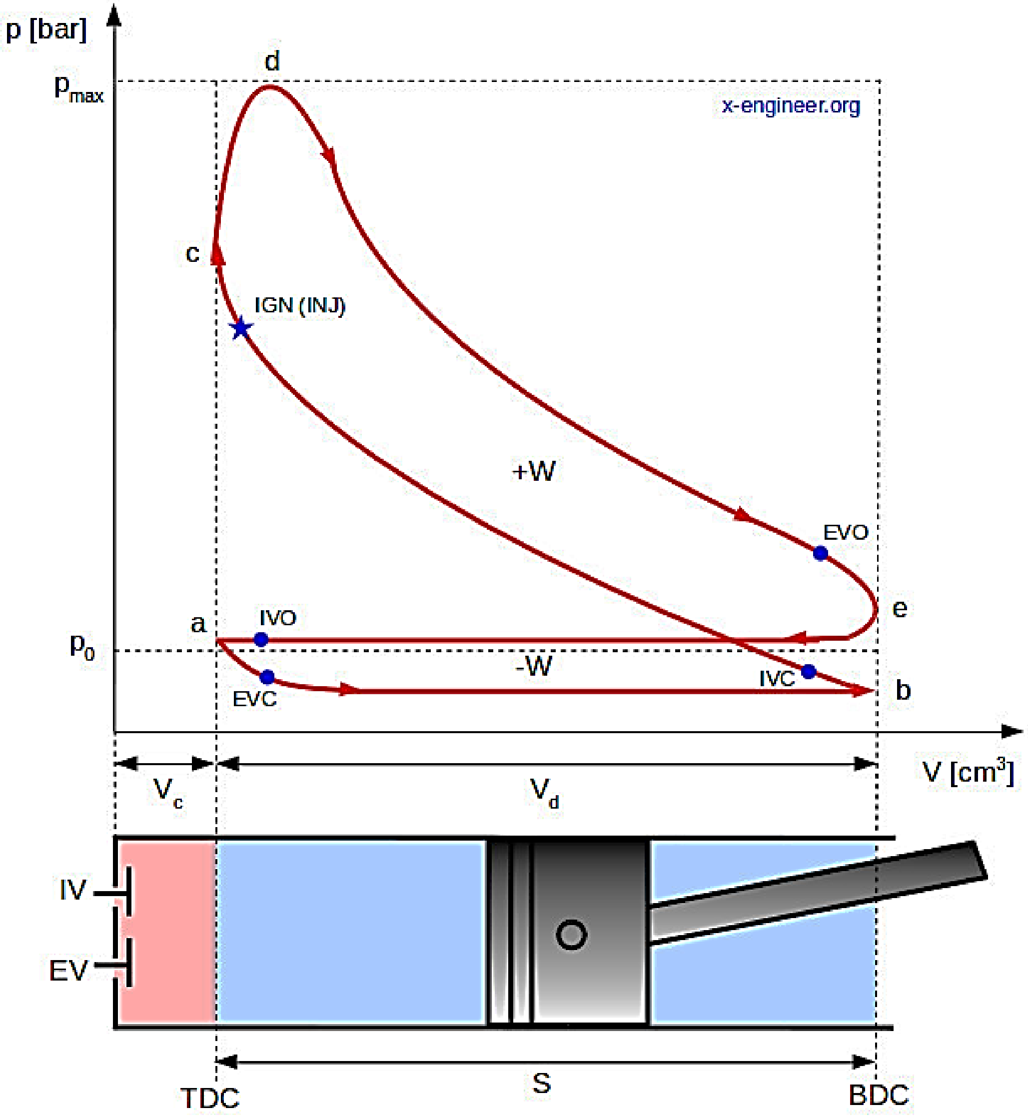
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$



# Actual Cycles and their Analysis



Idealised indicator diagram for four-stroke engine



Stylised actual indicator diagram for four-stroke engine

# Actual Cycles and their Analysis

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: already discussed.
2- Losses due to dissociation: already discussed.

The above losses are already represented in Fuel- Air cycles.

**3. Time loss:**

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.

In order that the maximum pressure is not reached too late in the expansion stroke, the time at which burning starts is varied by varying the spark timing (spark advance).

4. **Incomplete combustion loss**:

Fuel vapour, air, and residual gas are present in the cylinder, this makes it impossible to obtain perfect homogeneous mixture.. Therefore some fuel does not burn to $CO_2$ or partially burns to CO, and $O_2$ will appear in the exhaust. Energy release in actual engine is about 90 to 93% of fuel energy input.

5. **Direct heat loss**: is due to heat loss during combustion process and subsequent stroke.

Heat flows from cylinder gases through its walls, piston and cylinder head into the water jacket or cooling fins.

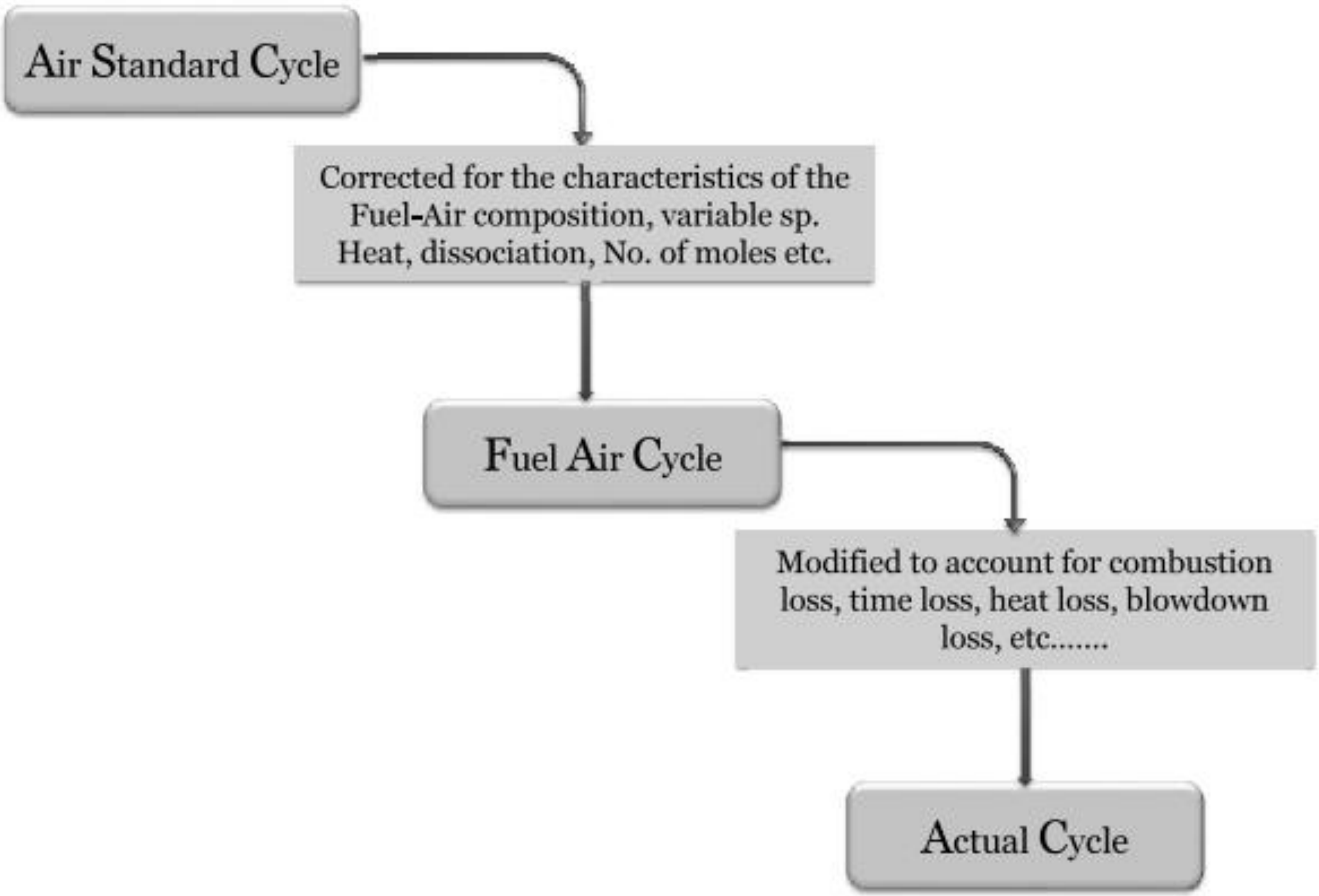
Some heat enters the piston head and flows through piston rings into the cylinder walls or carried away by lubricant oil.

Also, a part of the heat loss would be rejected in the exhaust at the end of the expansion stroke.

6. **Exhaust blow down loss**: is due to the reduction in the work done per cycle because of the exhaust valve opening before BDC which reducing cylinder pressure, causing the roundness of the end of the $p - V$ diagram.

**7. Pumping losses:** are due to expelling the exhaust gases and the induction of the fresh charge. In naturally aspirated engine this would be a negative work.

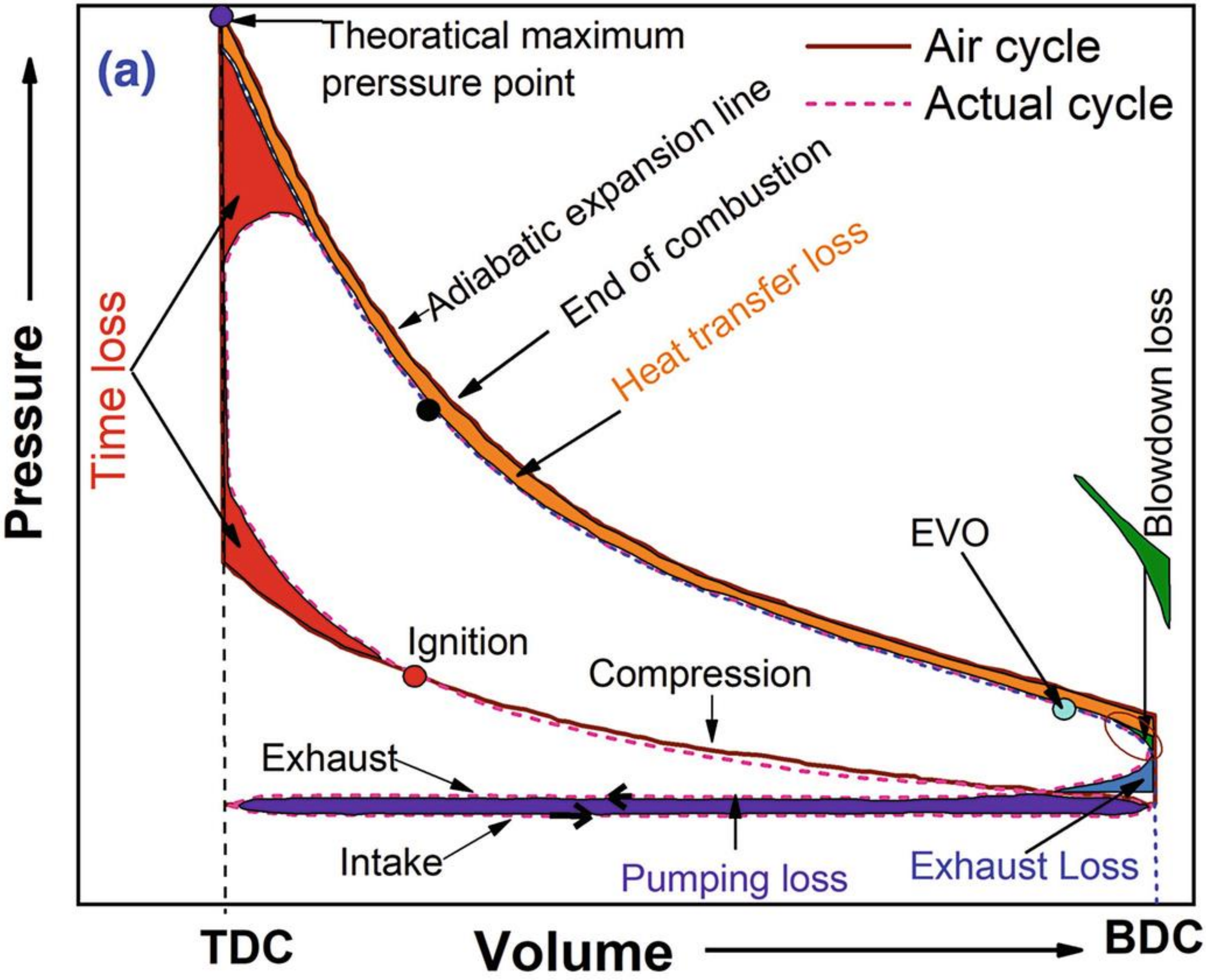
**8. Friction losses:** are due to the friction between the piston and cylinder walls, the various bearing, and the friction in the auxiliary equipment, such as pumps, fans, etc…



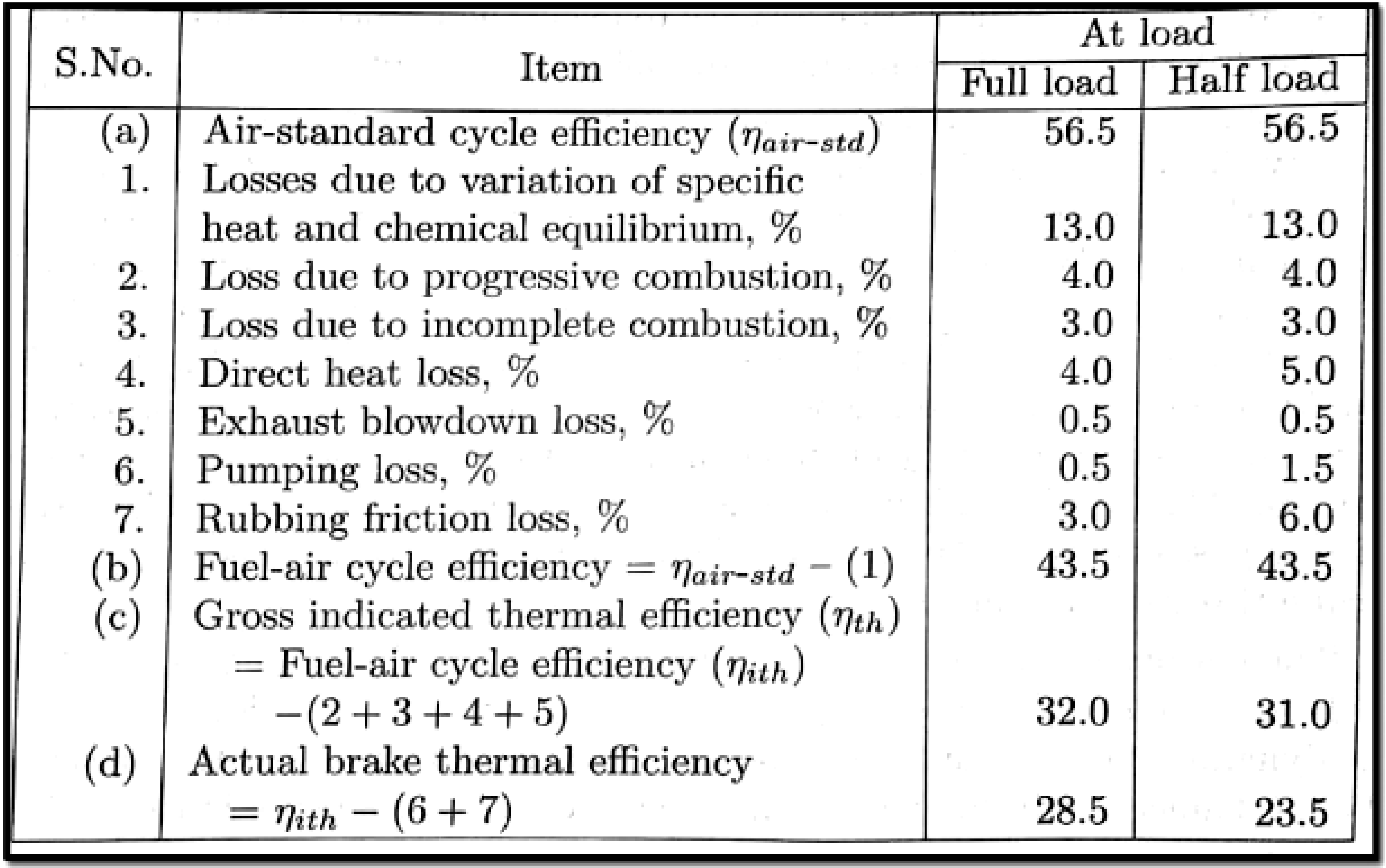
Corrected for the characteristics of the Fuel-Air composition, variable sp. Heat, dissociation, No. of moles etc.

Modified to account for combustion loss, time loss, heat loss, blowdown loss, etc.......

# Deconstruction of cycle losses



# Summary of Cycles Analysis



| S.No. | Item | At load | |
|---|---|---|---|
| | | Full load | Half load |
| (a) | Air-standard cycle efficiency ($\eta_{air-std}$) | 56.5 | 56.5 |
| 1. | Losses due to variation of specific heat and chemical equilibrium, % | 13.0 | 13.0 |
| 2. | Loss due to progressive combustion, % | 4.0 | 4.0 |
| 3. | Loss due to incomplete combustion, % | 3.0 | 3.0 |
| 4. | Direct heat loss, % | 4.0 | 5.0 |
| 5. | Exhaust blowdown loss, % | 0.5 | 0.5 |
| 6. | Pumping loss, % | 0.5 | 1.5 |
| 7. | Rubbing friction loss, % | 3.0 | 6.0 |
| (b) | Fuel-air cycle efficiency $= \eta_{air-std} - (1)$ | 43.5 | 43.5 |
| (c) | Gross indicated thermal efficiency ($\eta_{th}$) $=$ Fuel-air cycle efficiency ($\eta_{ith}$) $-(2+3+4+5)$ | 32.0 | 31.0 |
| (d) | Actual brake thermal efficiency $= \eta_{ith} - (6+7)$ | 28.5 | 23.5 |

**Typical losses in a gasoline engine for r = 8**