AIR STANDARD ASSUMPTIONS

In power engines, energy is provided by burning fuel within the system boundaries, i.e., internal combustion engines. The following assumptions are commonly known as the air-standard assumptions:

- The working fluid is air, which continuously circulates in a closed loop (cycle). Air is considered as ideal gas.
- All the processes in (ideal) power cycles are internally reversible.
- Combustion process is modeled by a heat-addition process from an external source.
- The exhaust process is modeled by a heat-rejection process that restores the working fluid (air) at its initial state.

Assuming constant specific heats, (@25°C) for air, is called *cold-air-standard assumption.*

Some Definitions for Reciprocation Engines

The reciprocation engine is one the most common machines that is being used in a wide variety of applications from automobiles to aircrafts to ships, etc.

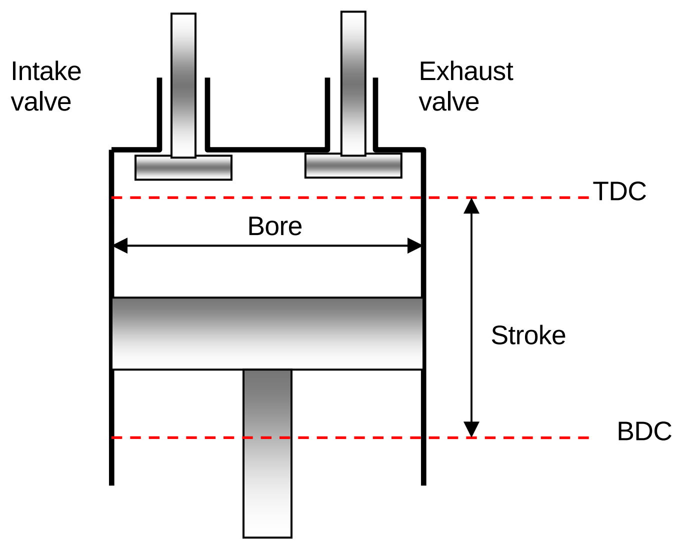

Fig. 1: Reciprocation engine.

Top dead center (TDC): The position of the piston when it forms the smallest volume in the cylinder.

Bottom dead center (BDC): The position of the piston when it forms the largest volume in the cylinder.

Stroke: The largest distance that piston travels in one direction.

Bore: The diameter of the piston.

Clearance volume: The minimum volume formed in the cylinder when the piston is at TDC.

Displacement volume: The volume displaced by the piston as it moves between the TDC and BDC.

Compression ratio: The ratio of maximum to minimum (clearance) volumes in the cylinder:

$$r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}}$$

Mean effective pressure (MEP): A fictitious (constant throughout the cycle) pressure that if acted on the piston will produce the work.

$$W_{net} = MEP \text{ x } A_{Piston} \text{ x Stroke} = MEP \text{ x Displacement vol.}$$

$$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} \quad (kPa)$$

An engine with higher MEP will produce larger net output work.

Internal Combustion Engines

1. spark ignition engines:
    - A mixture of fuel and air is ignited by a spark plug
    - Applications requiring power to about 225 kW (300 HP)
    - Relatively light and low in cost
2. compression ignition engine:
    - Air is compressed to a high enough pressure and temperature that combustion occurs when the fuel is injected
    - Applications where fuel economy and relatively large amounts of power are required. Low rpm.

Spark-Ignition (Gasoline) Engine

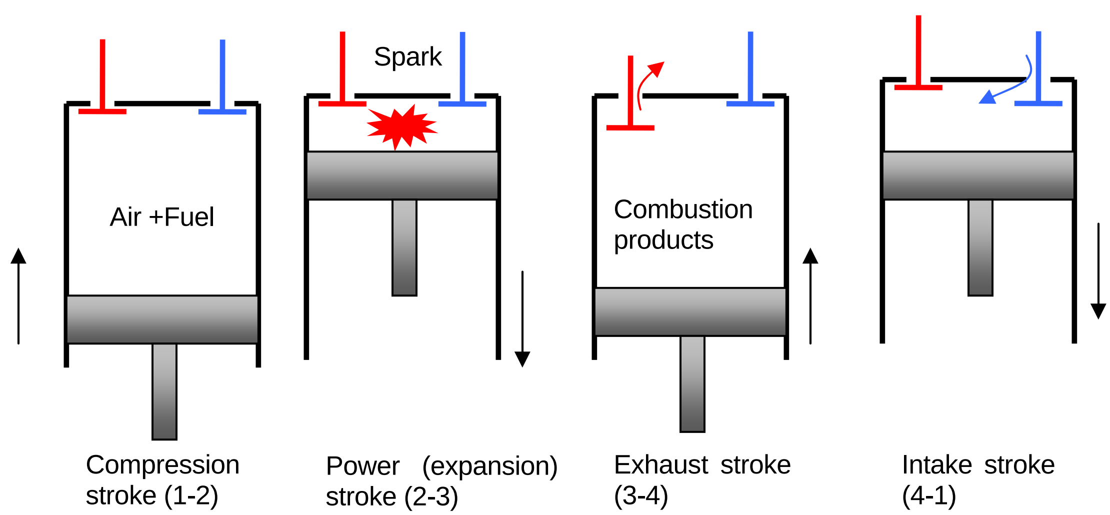

Fig. 2: Actual cycle for spark-ignition engines, four-stroke.

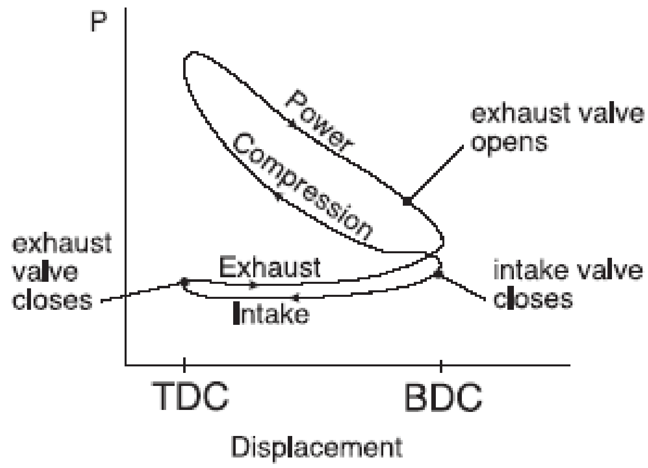

Fig. 3: P-v diagram for spark-ignition engines.

Otto Cycle

The Otto cycle is the ideal cycle for spark-ignition reciprocating engines. It serves as the theoretical model for the gasoline engine:

- Consists of four internally reversible processes
- Heat is transferred to the working fluid at constant volume

The Otto cycle consists of four internally reversible processes in series:

1-2	Isentropic compression
2-3	Constant-volume heat addition
3-4	Isentropic expansion
4-1	Constant-volume heat rejection

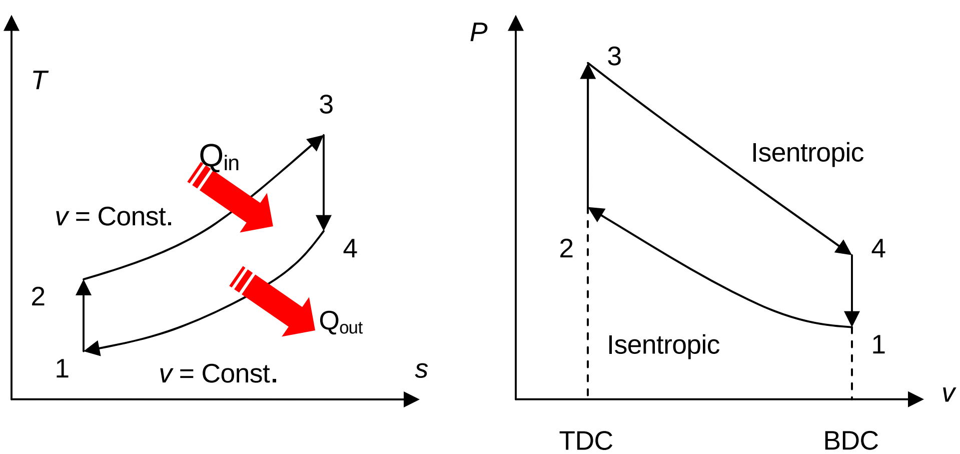

Fig. 4: *T-s* and *P-v* diagrams for Otto cycle.

The Otto cycle is executed in a closed system. Neglecting the changes in potential and kinetic energies, the 1st law, on a unit mass base, can be written:

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = \Delta u \quad (kJ/kg)$$

where

$$q_{in} = u_3 - u_2 = c_v (T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v (T_4 - T_1)$$

Thermal efficiency can be written :

$$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1 (T_4 / T_1 - 1)}{T_2 (T_3 / T_2 - 1)}$$

Processes 1-2 and 3-4 are isentropic, and $v_2 = v_3$ and $v_4 = v_1$. Thus,

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

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

where r is called the compression ratio:

$$r = \frac{V_{\max}}{V_{\min}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$$

Typical compression ratios for spark-ignition engines are between 7 and 10. The thermal efficiency increases as the compression ratio is increased. However, high compression ratios can lead to auto ignition or engine knock. Typical thermal efficiency for Otto cycles is 20-25%.

Diesel Engine

The diesel cycle is the ideal cycle for compression ignition engines. It is very similar to spark-ignition, expect the method of ignition. In diesel engine, air compressed to a temperature that is above the ignition temperature of the fuel.

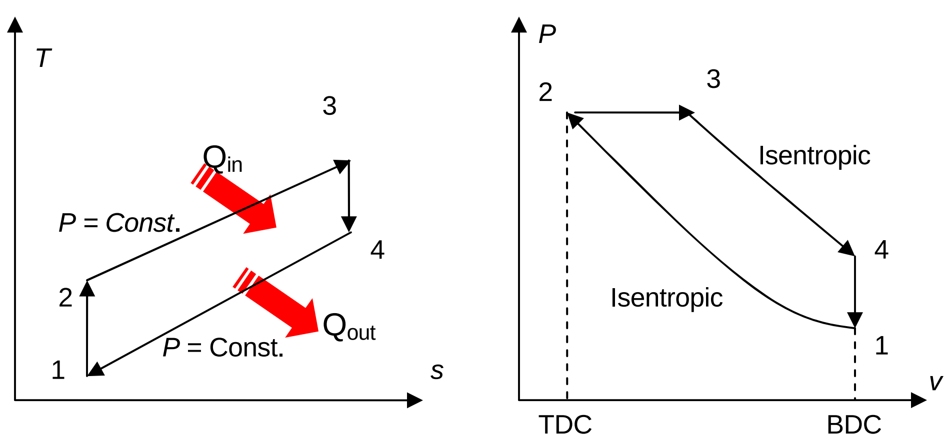

Fig. 5: *T-s* and *P-v* diagram of Diesel engine.

The thermal efficiency of the diesel engine under the cold air standard assumptions becomes:

$$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{1}{r^{k-1}} \underbrace{\left[\frac{r_c^k - 1}{k(r_c - 1)} \right]}_{=1 \text{ for Otto}}$$

where

$$r = \frac{V_{\max}}{V_{\min}} = \frac{v_1}{v_2}$$

We also define the cutoff ratio r_c, as the ratio of cylinder volumes after and before the combustion process (ignition period):

$$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

Comparison of the Otto and the Diesel Cycle

- $\eta_{Otto} > \eta_{Diesel}$ for the same compression ratio. However, the diesel cycle work on a much higher compression ratio; thus its thermal efficiency is higher. Typical thermal efficiency of a diesel cycle is 30-35%.
- Diesel engines burn the fuel more completely since they usually operate at lower rpm and air-fuel ratio is much higher than ignition-spark engines
- Diesel engines compression ratios are typically between 12 and 24, whereas spark-ignition (SI) engines are between 7 and 10. Thus a diesel engine can tolerate a higher compression ratio since only air is compressed in a diesel cycle and spark knock is not an issue

Dual Cycle (Limited Pressure Cycle)

Combustion process in internal combustion engines either as constant-volume (Otto cycle) or constant-pressure (Diesel cycle) heat addition is overly simplified and it is not realistic.

- Dual cycle is a better representation of the combustion process in both the gasoline and the diesel engines
- Both the Otto and the Diesel cycles are special cases of the dual cycle.

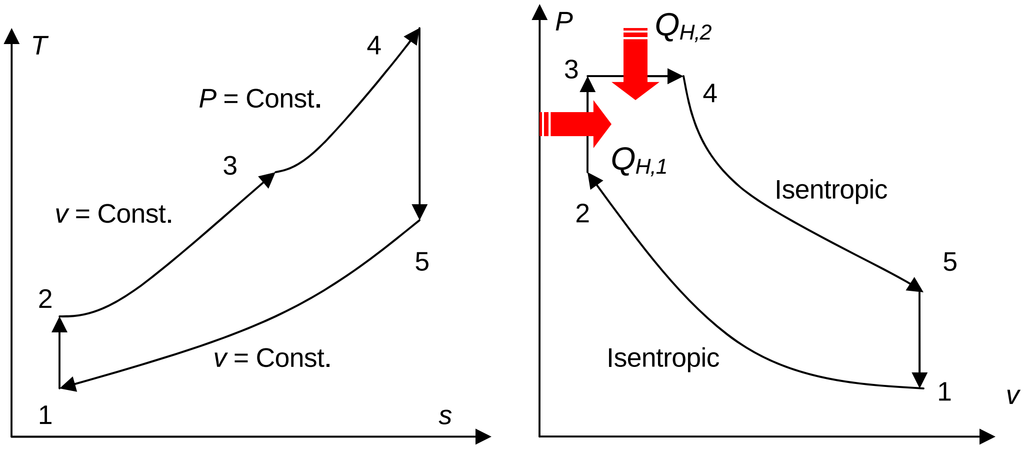

Fig. 6: *T*-*s* and *P*-*v* diagrams for an ideal dual cycle.

Defining:

$$r = \frac{v_1}{v_2} = \text{Compression ratio}$$

$$r_c = \frac{v_4}{v_3} = \text{Cutoff ratio}$$

$$r_p = \frac{P_3}{P_2} = \text{Pressure ratio}$$

The thermal efficiency of the dual cycle becomes:

$$\eta_{\text{Dual}} = 1 - \frac{r_p r_c^k - 1}{\left[(r_p - 1) + k r_p (r_c - 1)\right] r^{k-1}}$$

Note that when $r_p = 1$, we get the diesel engine efficiency.