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:

1- The working fluid is air, which continuously circulates in a closed loop (cycle). Air is considered as ideal gas.

2- All the processes in (ideal) power cycles are internally reversible.

3- Combustion process is modeled by a heat-addition process from an external source.

4- 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.

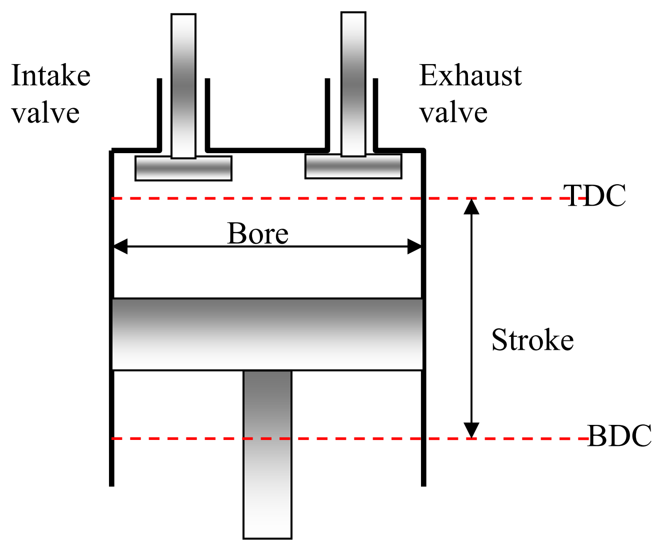

Fig. 3-1: Reciprocation engine.

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.

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

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

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

Spark-Ignition (Gasoline) Engine

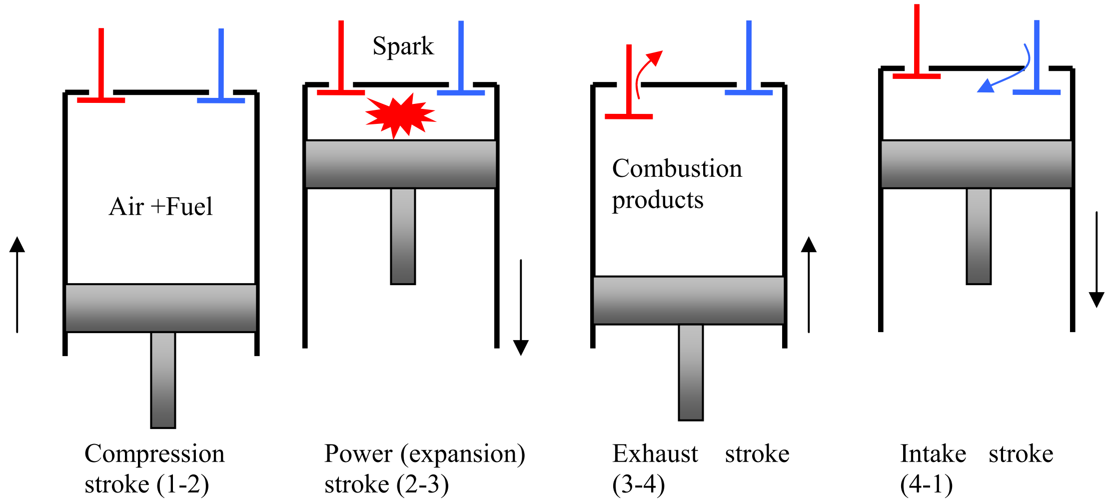

Fig. 3-2: Actual cycle for spark-ignition engines, four-stroke.

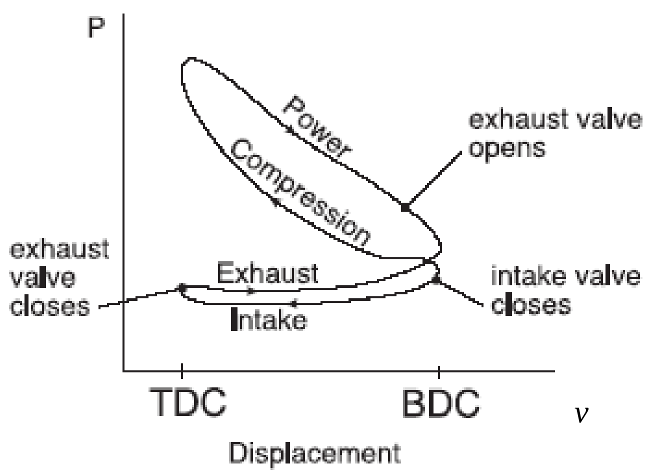

Fig. 3-3: *P-v* diagram for spark-ignition engines.

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

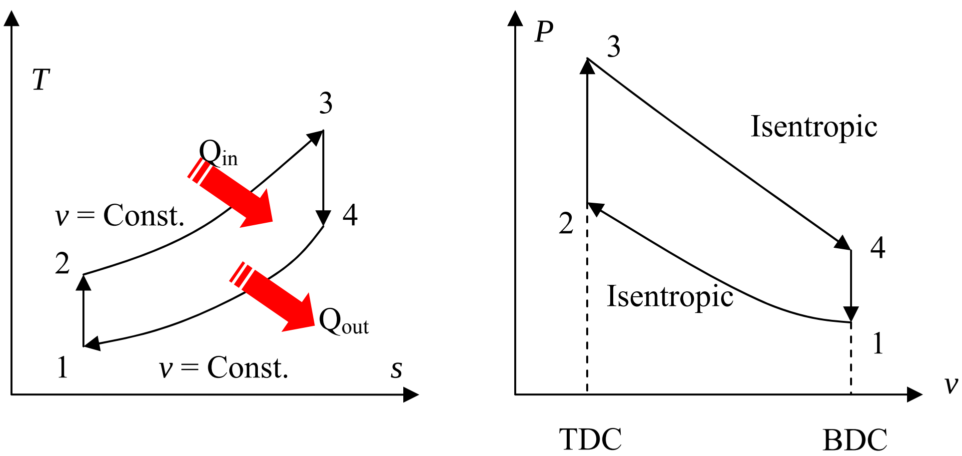

Fig. 3-4: T-s and P-v diagrams for Otto cycle.

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.*

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.

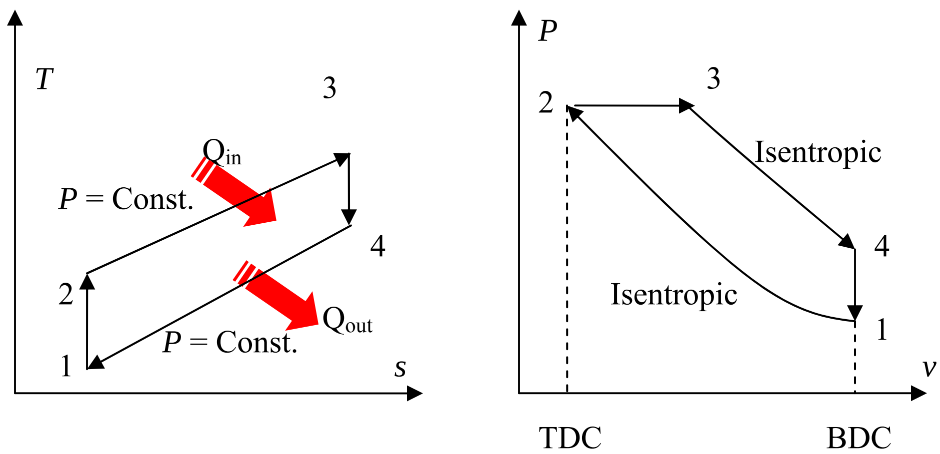

Fig. 3-5: *T-s* and *P-v* diagram of Diesel engine.

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
- 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 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.

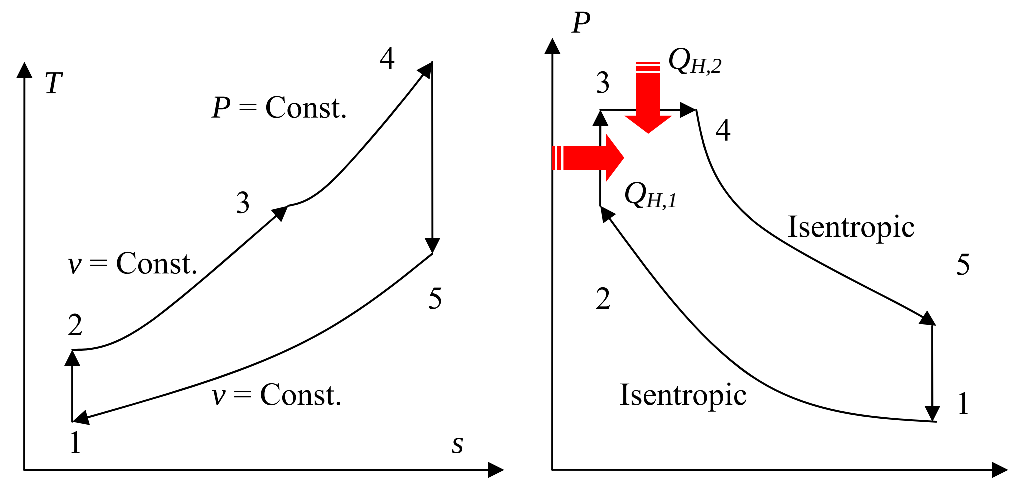

Fig. 3-6: *T*-*s* and *P*-*v* diagrams for an ideal dual cycle.

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.