GAS POWER CYCLES

Contents

1. Terminology Used in Gas Power Cycles

a) Air standard cycle: The thermodynamics cycle with **air** as the working fluid is called an air standard cycle.

b) Compression ratio ($r = r_c$): $r = \frac{\text{Total cylinder volume}}{\text{Clearance volume}} = \frac{V_C + V_S}{V_C}$-

The Compression ratio is limited by **two** practical considerations; ***Material strength*** and ***Octane number***. ***Higher the compression ratio better will be the performance of an engine.***

c) Thermal Efficiency: It is the ratio of work done to heat supplied by fuel.

$$\eta_{th} = \frac{\text{Work output}}{\text{Heat input}} = \frac{Q_1 - Q_2}{Q_1}$$

[Assuming no friction & heat losses, so ; $W = Q_1 - Q_2$]
Where, Q_1 = Heat addition & Q_2 = Heat rejection

d) Air standard efficiency: The efficiency of engine using air as the working medium is known as an "Air standard efficiency" or "***Ideal efficiency***".

□ The actual efficiency of a cycle is always **less** than the air standard efficiency of that cycle under ideal conditions. This is taken into account by introducing a new term "Relative efficiency".

$$\eta_{relative} = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$$

2-Internal combustion engines (ICE)

An Internal Combustion Engine is a heat engine which converts the heat energy to mechanical work, which the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber. *(HEAT ENERGY ⟶ MECHANICAL WORK)*

One of the major current goals of IC engine development is to achieve higher performance and thermal efficiencies. Three examples are: the thermodynamics of low heat rejection engines, the thermodynamics of exhaust gas dilution, and the thermodynamics of the ideal Otto cycle.

The simplified model of heat engine is a piston cylinder device which called reciprocating engine and the basic components are shown in Figure l.

Reciprocating engines are classified as spark-ignition (SI) engines and compression-ignition (CI) engines. In spark-ignition engines, the combustion of the air fuel mixture is initiated by a spark plug. But in CI engines, the air fuel mixture is self-ignited as a result of the compression temperature. The Otto and Diesel cycles are the ideal cycles for SI and CI reciprocating engines.

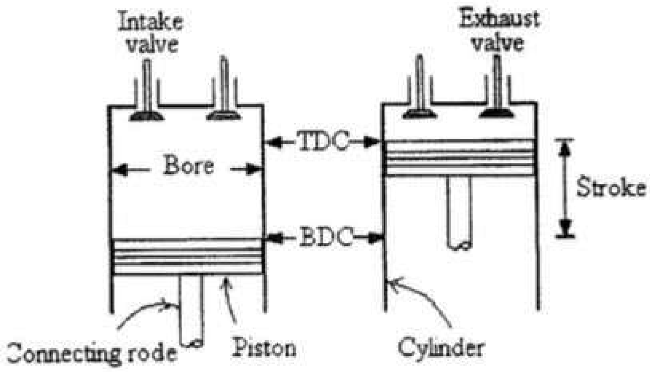


Figure 1: Basic components of reciprocating engine.

3- Air - Standard Cycles

The power cycles can be classified into two important fields. The first is the power generation which the work done output of the system such as Heat Engine. The second is the refrigeration and air conditioning which the work done input to the system such as Heat Pump. Both of it arc usually operating on a thermodynamic cycle. In the power generation systems, we will use the air standard cycles which the working fluid is returned to the initial state at the end of the cycle. To simplify the theoretical study "Standard Air Cycles" are introduced, ***some assumptions were made to study the air standard cycles such as:***

(a) The working fluid is air and always ideal gas.
(b)All processes are internally reversible.
(c) Heat added to the cycle is from external heat source.
(d)Heat rejected from the cycle is to the surrounding.

Classification According to the cycle of combustion.

1-Otto cycle,
2-Diesel cycle,
3-Dual cycle.

4- Air Standard Otto Cycle (Constant Volume Cycle):

The **Otto Cycle** is executed in a closed system and the change of kinetic and potential engines are disregarded. The air-standard-Otto cycle is the ideal cycle for the spark ignition, (SI), internal combustion engines. This cycle is applied (4- stroke and 2- stroke reciprocating engines) in petrol or gasoline engines, gas engine, and high-speed diesel (oil) engine. The thermodynamic analysis of four-strok cycle can be simplified if the air standard assumptions are used. The Otto cycle on P-v and T-s diagrams, is shown in Figure (2), and consists of following four processes:

Process 1-2: Reversible adiabatic compression of air (isentropic compression; $Q_{12} = 0$).
Process 2-3: Reversible Heat addition at constant volume; $Q_{23} = C_v (T_3 - T_2)$ **KJ.**
Process 3-4: Reversible adiabatic expansion of air (isentropic expression; $Q_{34} = 0$).
Process 4-1: Reversible Heat rejection at constant volume; $Q_{41} = C_v (T_4 - T_1)$ **KJ.**

This thermodynamic cycle is operated with isochoric (constant volume) heat addition and consists of two adiabatic processes and two constant volume changes.

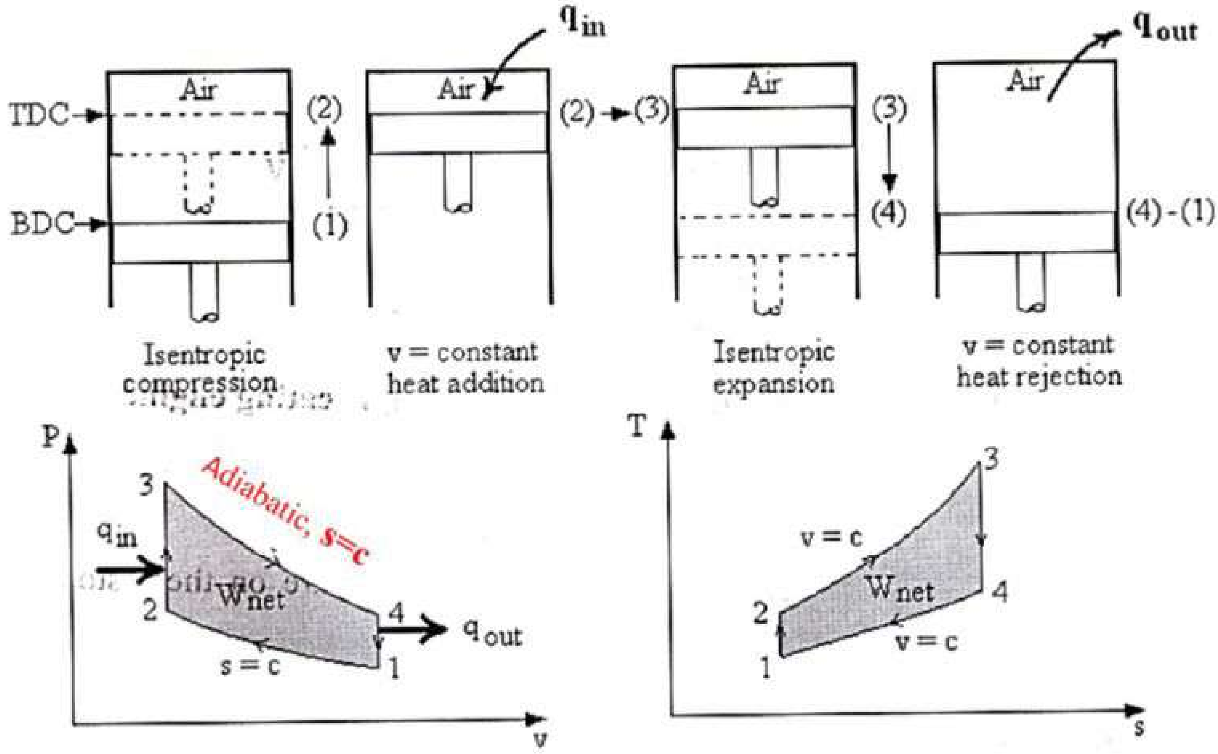


Figure 2: **Otto cycle and P-v, T-s diagrams**

Adiabatic Compression Process (1 – 2):

- ✓ At point 1 cylinder is full of air with volume V_1, pressure P_1 and temperature T_1.
- ✓ Piston moves from BDC to TDC and an ideal gas (air) is compressed isentropically to state point 2 through compression ratio, $r_c = r = V_1/V_2$ $\quad r = \frac{V_1}{V_2}$

Constant Volume Heat Addition Process (2 – 3):

- ✓ Heat is added at constant volume from an external heat source.
- ✓ The pressure rises and the ratio (r_p) or $(\alpha) = P_3/P_2$ $\quad r_p \text{ or } \alpha = \frac{P_3}{P_2}$ is called expansion ratio or pressure ratio.

Adiabatic Expansion Process (3 – 4):

- The increased high pressure exerts a greater amount of force on the piston and pushes it towards the BDC.
- Expansion of working fluid takes place isentropically and work done by the system.
- The volume ratio V_4/V_3 is called isentropic expansion ratio. $\frac{V_4}{V_3}$

Constant Volume Heat Rejection Process (4 – 1):

- Heat is rejected to the external sink at constant volume. This process is so controlled that ultimately the working fluid comes to its initial state 1 and the cycle is repeated. Otto cycle is called constant volume cycle because the heat is supplied to air at constant volume.

Thermal Efficiency of an Otto Cycle:

- Consider a unit mass of air ('m' kg of working fluid)
- Q_{add} = Heat supplied during the process 2–3, $\quad (q_1/m) = C_v\,(T_3 - T_2)$ kJ/kg
- Q_{rej} = Heat rejected during process 4 –1, $\quad (q_2/m) = C_v\,(T_4 - T_1)$ kJ/kg

Work done: $\therefore W = q_1 - q_2$

$\therefore W = C_V\,(T_3 - T_2) - C_V(T_4 - T_1)$

Since processes 1-2 and 3-4 are adiabatic processes, the heat transfer during the cycle takes place only during processes 2-3 and 4-1 respectively.

Therefore, thermal efficiency can be written as,

η_{th} **= (Heat added - Heat rejected) / Heat added** = $\eta = \frac{Q^{\uparrow} - Q^{\downarrow}}{Q^{\downarrow}} = 1 - \frac{Q^{\uparrow}}{Q^{\downarrow}}$

$$\eta = \frac{Work\ done}{Heat\ supplied} = \frac{W}{q_1} = \frac{C_V\,(T_3 - T_2) - C_V(T_4 - T_1)}{C_V\,(T_3 - T_2)} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1} \qquad \therefore T_2 = T_1 r^{\gamma-1}$$

- **For Isentropic expansion process (3 – 4),** $\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$

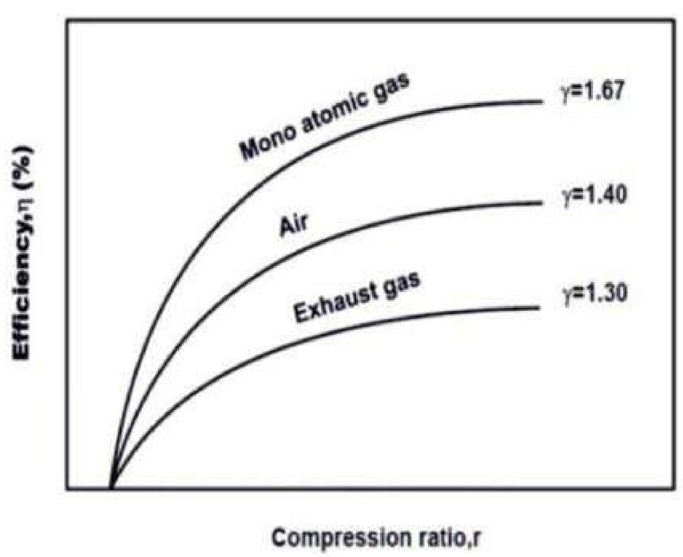
$$\therefore T_3 = T_4\left(\frac{V_4}{V_3}\right)^{\gamma-1} \qquad \therefore T_3 = T_4\left(\frac{V_1}{V_2}\right)^{\gamma-1}\ (\because V_1 = V_4\,, V_2 = V_3) \qquad \therefore T_3 = T_4(r)^{\gamma-1}$$

- **From above equations, we get,**

$$\eta_{otto} = 1 - \frac{(T_4 - T_1)}{T_4\,r^{\gamma-1} - T_1\,r^{\gamma-1}} = 1 - \frac{(T_4 - T_1)}{r^{\gamma-1}(T_4 - T_1)}$$

$$\therefore \boldsymbol{\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}}$$

From the above equation of thermal efficiency for otto cycle, it can be observed that the efficiency of the Otto cycle is mainly the function of compression ratio for the given ratio of $\mathbf{C_p}$ and $\mathbf{C_v}$, and it is clear that the thermal efficiency is very dependent on the compression ratio, r, and the specific heat ratio, $\boldsymbol{\gamma = C_p/C_v}$ as shown in Figure 2. The Otto cycle thermal efficiency increases with increasing the compression ratio r and the specific heat ratio $\boldsymbol{\gamma}$.



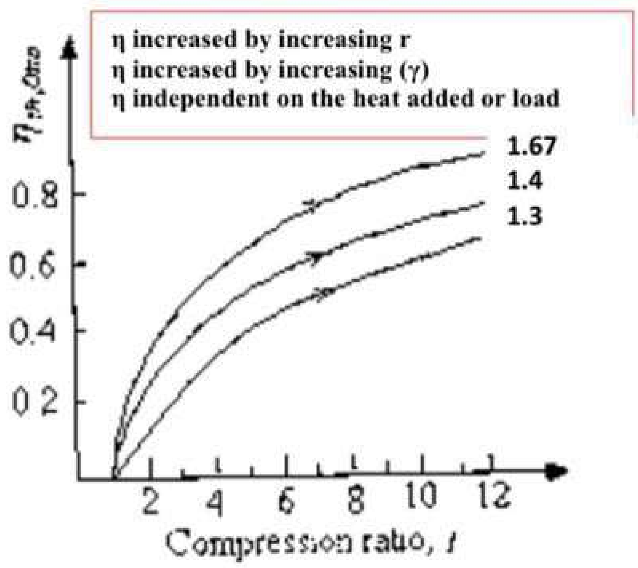


Figure 2: Shows the variation of air standard efficiency of Otto cycle with compression ratio (r)and (γ).