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Compression Ratio and Thermal Efficiency

Compression Ratio – Otto Engine

The **compression ratio**, **CR**, is defined as the ratio of the volume at bottom dead center and the volume at top dead center. It is a key characteristics for many internal combustion engines. In the following section, it will be shown that the **compression ratio** determines the **thermal efficiency** of used thermodynamic cycle of the combustion engine. In general, it is desired to have a high compression ratio, because it allows an engine to reach higher thermal efficiency.

For example, let assume an Otto cycle with compression ratio of CR = 10 : 1. The volume of the chamber is 500 cm^3 = 500×10^{-6} m^3 (0.5l) prior to the compression stroke. For this engine **a**ll required volumes are known:

- $V_1 = V_4 = V_{max} = 500\times10^{-6}$ m^3 (0.5l)
- $V_2 = V_3 = V_{min} = V_{max}$ / CR = 55.56 $\times10^{-6}$ m^3

Note that ($V_{max} – V_{min}$) x number of cylinders = total engine displacement.

Thermal Efficiency for Otto Cycle

In general the **thermal efficiency**, η_{th}, of any heat engine is defined as the ratio of the work it does, **W**, to the heat input at the high temperature, Q_H.

$$\eta_{th} = \frac{W}{Q_H}$$

The **thermal efficiency**, η_{th}, represents the fraction of **heat**, $\mathbf{Q_H}$, that is converted **to work**. Since energy is conserved according to the **first law of thermodynamics** and energy cannot be be converted to work completely, the heat input, Q_H, must equal the work done, W, plus the heat that must be dissipated as **waste heat** $\mathbf{Q_C}$ into the environment. Therefore we can rewrite the formula for thermal efficiency as:

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$$\eta_{th} = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

The heat absorbed occurs during combustion of fuel-air mixture, when the spark occurs, roughly at constant volume. Since during an isochoric process there is no work done by or on the system, the **first law of thermodynamics** dictates *ΔU = ΔQ*. Therefore the heat added and rejected are given by:

$Q_{add} = mc_v (T_3 - T_2)$

$Q_{out} = mc_v (T_4 - T_1)$

Substituting these expressions for the heat added and rejected in the expression for thermal efficiency yields:

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

We can simplify the above expression using the fact that the processes **1 → 2** and from **3 → 4** are adiabatic and for an adiabatic process the following p,V,T formula is valid:

$$\left[\frac{V_2}{V_1}\right]^{\kappa} = \left[\frac{T_1}{T_2}\right]^{\frac{\kappa}{\kappa-1}}$$

It can be derived that:

$$\frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\kappa-1}$$

In this equation, the **ratio V_1/V_2** is known as the **compression ratio, CR**. When we rewrite the expression for thermal efficiency using the compression ratio, we conclude the **air-standard Otto cycle** thermal efficiency is a function of **compression ratio** and **$\kappa = c_p/c_v$**.

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \rightarrow \eta_{Otto} = 1 - \left(\frac{V_2}{V_1}\right)^{\kappa-1} = 1 - \frac{1}{CR^{\kappa-1}}$$

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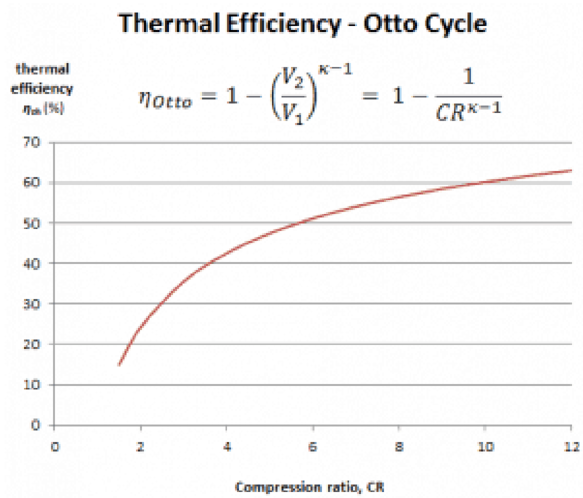

Thermal efficiency for Otto cycle – κ = 1.4

It is very useful conclusion, because it is desirable to achieve a **high compression ratio** to extract more mechanical energy from a given mass of air-fuel mixture. A higher compression ratio permit the same combustion temperature to be reached with less fuel, while giving a longer expansion cycle. This creates more mechanical power output and **lowers the exhaust temperature**. Lowering the exhaust temperature causes the lowering of the energy rejected to the atmosphere. This relationship is shown in the figure for κ = 1.4, representing ambient air.

+ References:

See above:

Otto Cycle

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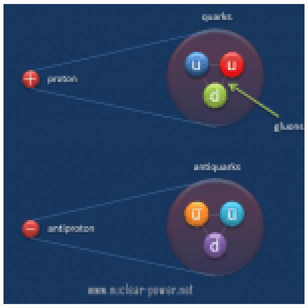

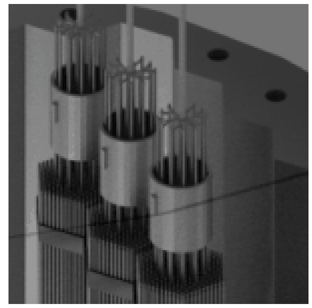

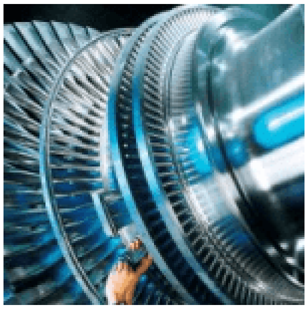

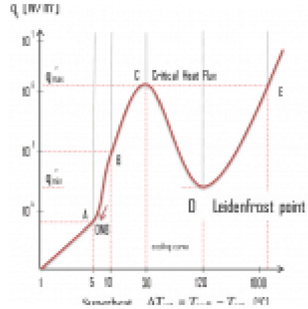

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