## Air standard efficiency (ASE)

The actual efficiency of an engine is the ratio of heat used to that supplied:

$$\frac{\text{heat supplied - heat rejected}}{\text{heat supplied}}$$

Air standard efficiency is taken as the ideal efficiency of an internal combustion engine. In this case we imagine air is used instead of petrol or fuel oil mixed with air to form a gas. ASE assumes:

(a) No transfer of heat between the working surfaces and the air
(b) Instantaneous and complete combustion
(c) No change in volume during the combustion (constant volume)
(d) Specific heat capacity is assumed to be constant.

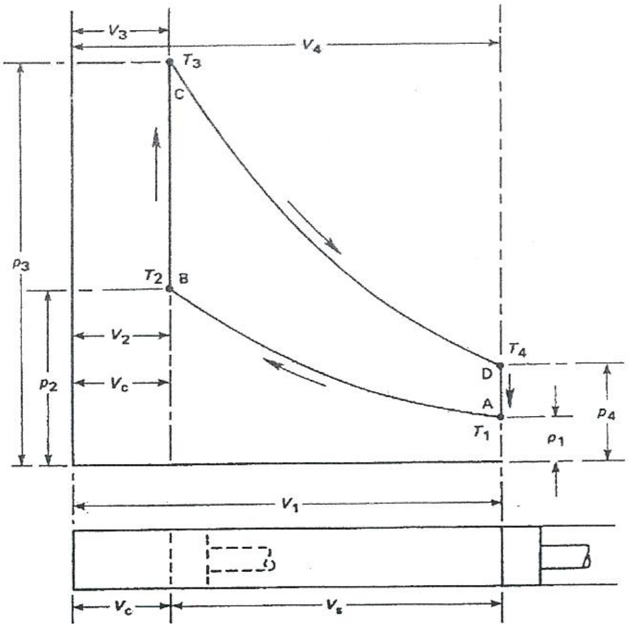
The last assumption is not possible even for air as the specific heat capacity rises with the rise of temperature. Heat transfer does take place and combustion is not complete or instantaneous thus true constant volume burning does not take place. From these statements it is obvious that the 'actual' efficiency of an engine will always fall short of the 'ideal' or air standard.

If an engine could convert all the heat supplied to it into mechanical work, its efficiency would be 100%. This would mean that whatever the temperature of the charge reached during combustion, the final temperature would have to be absolute zero. This implies that the exhaust gases would have to be -273"C. Such a condition is quite impossible, but it is the difference between the initial and final temperatures which determines the efficiency, and their difference is governed by the compression and expansion ratio.

The charge of air and fuel is compressed adiabatically, in the Figure, from A to B. Heat is then liberated by combustion, the temperature rising but the volume remaining constant. The expansion or working stroke takes place form C to D. Heat is then exhausted at constant volume D to A.

Let $c_v$ be the specific heat capacity at constant volume and $T_1$, $T_2$, $T_3$ and $T_4$ represent the various temperatures during the cycle. Consider 1 kg of working gases.

heat supplied from B to C = $c_v (T_3 - T_4)$
heat rejected from D to A = $c_v (T_4 - T_1)$
therefore work done = heat supplied – heat rejected
= $c_v (T_3 - T_4) - c_v (T_4 - T_1)$



$$\text{and efficiency} = \frac{\text{work done}}{\text{heat supplied}}$$

$$= \frac{\text{heat supplied} - \text{heat rejected}}{\text{heat supplied}}$$

$$= \frac{(T_3 - T_2) - (T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Now compression ratio

$$CR = r = \frac{V_1}{V_2}$$

and expansion ratio

$$= \frac{V_4}{V_3} = r$$

therefore

$$\frac{1}{r} = \frac{V_2}{V_1} \, and \, \frac{V_3}{V_4}$$

Compression is adiabatic according to $pV^\gamma = C$ where

$$\gamma = \frac{c_p}{c_v}$$

therefore

$$p_1 V_1^\gamma = p_2 V_2^\gamma \; and \; p_1 V_1 V_1^{\gamma-1} = p_2 V_2 V_2^{\gamma-1}$$

As pv = nRT, substitute $p_1$ $V_1$ and $p_2$ $V_2$, therefore

$$nR\,T_1\,V_1^{\gamma-1} = nR\,T_2\,V_2^{\gamma-1}$$

$$T_1\,V_1^{\gamma-1} = T_2\,V_2^{\gamma-1}$$

And

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

Expansion is also adiabatic, therefore:

$$T_3\,V_3^{\gamma-1} = T_4\,V_4^{\gamma-1}$$

And

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} = \frac{T_1}{T_2}$$

therefore

$$\frac{T_4}{T_3} = \frac{T_1}{T_2} \mathit{and}\ T_4 = \frac{T_1 T_3}{T_2}$$

and efficiency

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

$$= 1 - \frac{(T_1 T_3 / T_2) - T_1}{T_3 - T_2}$$

$$= 1 - \frac{T_1}{T_2}\frac{T_3 - T_2}{T_3 - T_2}$$

$$= 1 - \frac{T_1}{T_2}$$

$$= 1 - \left(\frac{1}{r}\right)^{\gamma-1}$$

## <u>Actual engine thermal efficiencies</u>

Brake thermal efficiencies range between 17.5 and 36%, but engines out of tune etc., operate well below these figures. The design of the engine, the fuel used and the compression ratio are main factors influencing its thermal efficiency, together with the conditions under which the engine is operating. Fuel consumption is heavier at part throttle and part load conditions. A weaker mixture in conjunction with good ignition qualities results in higher efficiency. At the higher engine speeds, efficiency is improved and good combustion chamber design is important together with a high octane fuel. Carburetion for the petrol engine and fuel injection for the CI oil engine play an important role in achieving higher efficiencies. The problem of attaining high thermal efficiency is a vast but interesting one, and in the light of conservation of energy a very important one.