4.0 IDEAL CYCLES IN ENGINES (AIR STANDARD CYCLES)

4.0 Air Standard Cycles

Internal combustion engines are classified into two groups which are: (a) the rotary and (b) the reciprocating internal combustion engines. A good example of the rotary internal combustion engine is the gas turbine. The reciprocating internal combustion engines are further classified into two main groups: (i) Spark Ignition engines and (ii) Compression Ignition engines and these engines operating on Otto and Diesel cycles respectively.

In these engines, the products of combustion are expelled to its surroundings and this makes these engines operate on open cycles. For each cycle, fresh charge (a mixture of air and fuel) is introduced. To study the operations and performances of these engines, they are represented with theoretical engines operating on thermodynamic cycles and these theoretical engines are referred to as **air standard engines.** They are called air standard engines because their working fluid is taken to be majorly air. In these engines, heat is added from an external source as opposed to burning fuel and a heat sink is provided as opposed to exhaust, thus returning the air back to its original state.

The following assumptions are made for the air standard cycle:

- The working fluid (air) has a constant mass throughout the entire air cycle and air is taken to be ideal.
- The air maintains a constant specific heat capacity throughout the cycle.
- The combustion process is replaced by a heat transfer process from an external heat source.
- The cycle is completed by the heat transfer to the surrounding in contrast to the exhaust and the intake processes of an actual engine.
- All the processes are internally reversible.

4.1 GAS POWER CYCLES

4.1.1 Otto Cycle

This cycle which is named after the inventor, Nicolaus Otto, whose engine, operated on this principle in 1876.

The diagram for the ideal air standard Otto cycle is shown below:

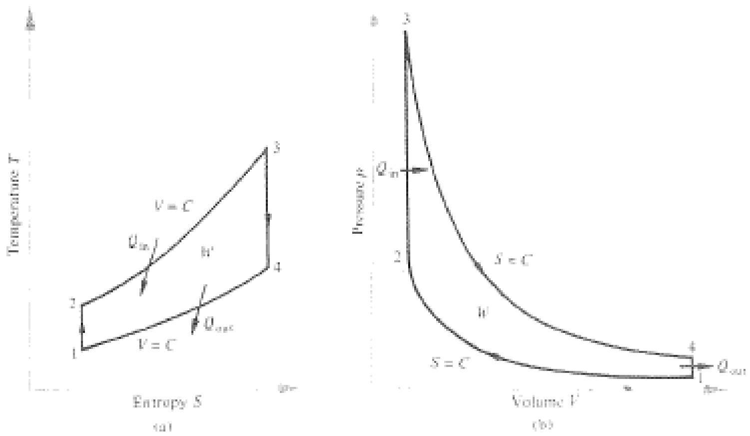

Figure 1: (a) The T-S diagram for an air-standard Otto cycle (b) The P-V diagram for the air-standard Otto cycle

Process 1 -2: Isentropic compression of air takes place from state 1 to state 2.

Process 2-3: constant volume heat addition takes place from state 2 to state3.

Process 3–4: Isentropic expansion occurs from state 3 to state 4.

Process 4-1: heat rejection at constant volume occurs from state 4 to state 1.

Q_{in} is the heat supplied at constant volume

$$Q_{in} = C_v(T_3 - T_2) \quad (1)$$

Heat rejected Q_{out}

$$Q_{out} = C_v(T_4 - T_1) \quad (2)$$

Thermal efficiency $$\eta = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} \quad (3)$$

For the isentropic processes, the following expressions hold

$Tv^{\gamma - 1}$ = constant (4a)

Where,

γ is the specific heat capacity ratio or adiabatic index of air.

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = \frac{T_3}{T_4} = \gamma_v^{\ \gamma-1} \tag{4b}$$

Where γ_v = compression ratio

Since,

$$T_3 = T_4\gamma_v^{\ \gamma-1} \text{ and } T_2 = T_1\gamma_v^{\ \gamma-1} \tag{5}$$

Substituting these expressions into equ. (3), gives:

$$\eta = 1 - \frac{(T_4 - T_1)}{(T_4 - T_1)\gamma_v^{\ \gamma-1}} \tag{6}$$

Therefore,

$$\eta = 1 - \frac{1}{\gamma_v^{\ \gamma-1}} \tag{7}$$

QUESTION 1

A petrol engine has a bore 80mm, a stroke of 110mm and a clearance volume of 53.80 cm^3. Calculate thermal efficiency of the petrol engine based on air standard Otto cycle.

Solution

The engine bore D = 80mm = 8 cm = 0.08 m

Engine Stroke L = 110mm = 11cm= 0.11m

Thermal Efficiency $\eta_{th} = 1 - \frac{1}{\gamma_c^{\ \gamma-1}}$

Total Cylinder Volume $V = V_c + V_s$

The clearance volume V_c

Swept Volume $V_s = \frac{\pi D^2}{4} L$

Compression ratio $\gamma_c = \frac{V}{V_c}$

Where,

γ_c = compression ratio

γ = specific heat ratios

The swept volume $V_s = \frac{\pi(8)^2}{4} 11$ = 552.92 cm^3

Total engine volume $V = V_c + V_s$ = 53.8 + 552.92 = 606.72 cm^3

The compression ratio $\gamma_c = \dfrac{V}{V_c} = \dfrac{606.72}{53.8} = 11.28$

γ = 1.4

Thermal Efficiency $\eta_{th} = 1 - \dfrac{1}{\gamma_c^{\gamma-1}}$ = 1 - $\dfrac{1}{(11.28)^{1.4-1}}$ = 0.62 or 62%

Practice Questions

[1]. An air standard Otto cycle has a compression ratio of 8.5 and has air conditioned at the beginning of compression of 100 kPa and 25 ˚C. The heat added is 1400kJ/kg. Determine (a) pressures at the points in the cycle states (b) the engine's thermal efficiency (c) the mean effective pressure

[2]. An engine operates on the air standard Otto cycle. The cycle work is 900kJ/kg, the maximum temperature is 2800 ˚C and the temperature at the end of isentropic compression is 600 ˚C. Determine the engine's compression ratio.

[3]. In an air standard Otto cycle, the maximum and minimum temperatures are 1400 ˚C and 25 ˚C. The heat supplied per kg of air is 800kJ. Calculate the compression ratio and the thermal efficiency. Calculate also the ratio of maximum to minimum pressures in the cycle.