6-The Dual Combustion Cycle OR The Limited Pressure Cycle

This is a cycle in which the addition of heat is partly at constant volume and partly at constant pressure. The cycle is applied in medium speed and high speed diesel engines. The engine may be 4 or 2 strokes.

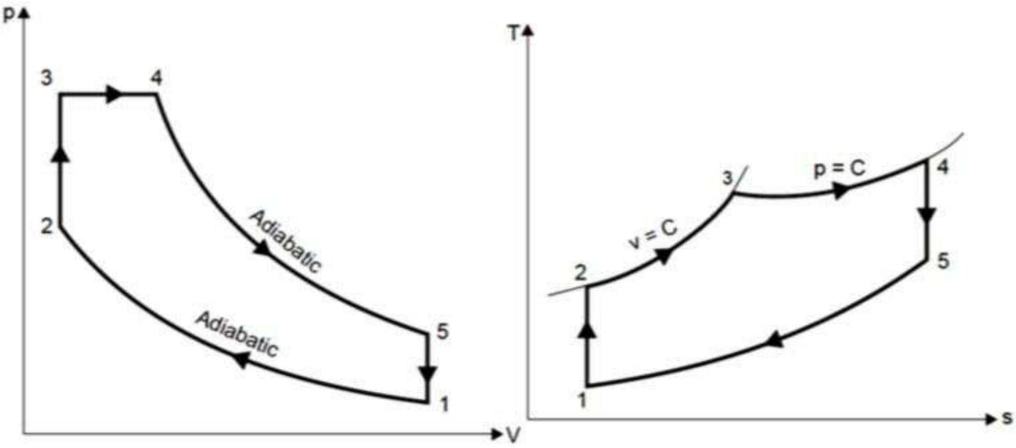

Figure 5: P-V and T-S diagrams of Dual cycle.

Adiabatic Compression Process (1 – 2):

□ Isentropic (Reversible adiabatic) compression with the compression ratio $\mathbf{r_c}$ (r) = V_1/V_2

Constant Volume Heat Addition Process (2 – 3):

□ The heat is supplied at constant volume with explosion ratio or pressure ratio (α) rp= P_3/P_2

Constant Pressure Heat Addition Process (3 – 4):

□ The heat supply is stopped at point 4 which is called the cut – off point and the volume ratio ($r_{off} = \beta = V_3/V_2 = \rho$) is called cut off ratio.

Adiabatic Expansion Process (4 – 5):

□ Isentropic expansion of air with $V_5/V_4 = r_e$= isentropic expansion ratio.

Constant Volume Heat Rejection Process (5 – 1):

□ In this process heat is rejected at constant volume.

The high-speed Diesel engines work on a cycle which is slight modification of the Dual cycle.

Thermal Efficiency for Dual Cycle:

□ Consider unit mass of air undergoing the cyclic change.

□ **Heat supplied,**

$$q_1 = q_{2-3} + q_{3-4} = C_V(T_3 - T_2) + C_P(T_4 - T_3)$$

□ **Heat rejected during process 5 – 1,**

$$q_2 = C_V(T_5 - T_1)$$

Work done, $W = q_1 - q_2 = C_V(T_3 - T_2) + C_P(T_4 - T_3) - C_V(T_5 - T_1)$

□ Thermal efficiency

$$\eta = \frac{Work\ done}{Heat\ supplied} \quad \therefore \eta = \frac{C_V(T_3 - T_2) + C_P(T_4 - T_3) - C_V(T_5 - T_1)}{C_V(T_3 - T_2) + C_P(T_4 - T_3)}$$

$$\therefore \eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)}$$

□ **For adiabatic compression process (1 – 2),**

$$r = \frac{V_1}{V_2} \Rightarrow \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} \Rightarrow P_2 = P_1 r^{\gamma} \Rightarrow T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1\, r^{\gamma-1}$$

□ **For constant volume heat addition process (2 – 3);**

$$V_3 = V_2 = \frac{V_1}{r} \Rightarrow \alpha = \frac{P_3}{P_2}\ (Pressure\ ratio) \Rightarrow \therefore P_3 = P_2\alpha = P_1 r^{\gamma}\alpha$$

$$T_3 = T_2\frac{P_3}{P_2} = T_2\,\alpha \Rightarrow \therefore T_3 = T_1\, r^{\gamma-1}\alpha$$

□ **For constant pressure heat addition process (3 – 4)**

$$\therefore T_4 = T_3\,\rho \Rightarrow \therefore T_4 = T_1\, r\gamma{-}1\rho\alpha$$

$$P_3 = P_4 = P_1 r^{\gamma}\alpha \Rightarrow \rho = \frac{V_4}{V_3}\ (Cutoff\ ratio) \Rightarrow T_4 = T_3\frac{V_4}{V_3}$$

For adiabatic expansion process (4 – 5), $P_4V_4^{\gamma} = P_5V_5^{\gamma}$

$$\eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \qquad \therefore \eta = 1 - \frac{(T_1\,\alpha\,\rho^{\gamma} - T_1)}{(T_1\,r^{\gamma-1}\alpha - T_1\,r^{\gamma-1}) + \gamma(T_1\,r^{\gamma-1}\alpha\rho - T_1\,r^{\gamma-1}\alpha)}$$

$$\therefore \eta = 1 - \frac{(\rho^{\gamma}\alpha - 1)}{[r^{\gamma-1}\{(\alpha - 1\alpha) + \gamma\alpha(\rho - 1)\}]}$$

$$\boldsymbol{\therefore \eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{(\alpha\rho^{\gamma} - 1)}{(\alpha - 1) + \gamma\alpha(\rho - 1)}\right]}$$

From the above equation, it can be seen the thermal efficiency of a Dual cycle can be increased by supplying a greater portion of heat at constant volume (high value of α) and smaller portion at constant pressure (low value of ρ).

- In the actual high speed Diesel engines operating on this cycle, it is achieved by early fuel injection and an early cut-off.
- It is to be noted that Otto and Diesel cycles are special cases of the Dual cycle.
- If $\rho = 1$ ($V_3 = V_4$)

Hence, there is no addition of heat at constant pressure. Consequently, the entire heat is supplied at constant volume and the cycle becomes the Otto cycle.

By substituting $\rho = 1$ in equation, we get,

$$\eta = 1 - \frac{1}{r^{(\gamma-1)}} = Efficiency\ of\ Otto\ cycle$$

- Similarly, if $\alpha = 1$, the heat addition is only at constant pressure and cycle becomes Diesel cycle. By substituting $\alpha = 1$ in equation, we get

$$\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{(\rho^{\gamma} - 1)}{\gamma(\rho - 1)}\right] = Efficiency\ of\ Diesel\ cycle$$

7-Comparison of Otto, diesel and Dual Cycles:

Following are the important variable factors which are used as a basis for comparison of the cycles:

A. Compression ratio
B. Maximum pressure
C. Heat supplied
D. Heat rejected
E. Net work.

A. For the Same Compression Ratio and the Same Heat Input

$$\eta = 1 - \frac{Heat\ Rejected}{Heat\ Supplied} = 1 - \frac{q_2}{q_1}.$$

As we know, the quantity of heat rejected from each cycle is represented by the area on the T– S diagram. From efficiency equation; it is clear that the cycle which has the least heat rejected will have the highest efficiency.

$$\boldsymbol{\therefore \eta Otto > \eta Dual > \eta Diesel}$$

B. Same Maximum Pressure and Temperature

When pressure is the limiting factor in engine design, it becomes necessary to compare the air standard cycles on the basis of same maximum pressure & temperature.

From same above efficiency equation; it is clear that the heat rejected is same for all the three cycles. Hence with the same heat rejected, the cycle with greater heat addition is more efficient.

$\therefore \eta Diesel > \eta Dual > \eta Ott.$

C. For Constant Maximum Pressure and Heat Input

Also from same above efficiency equation, for the same amount of heat supplied the cycle with less heat rejected has a higher value of thermal efficiency.

$\therefore \eta Diesel > \eta Dual > \eta Otto$

8- Worked of air Standard Cycles (H.W.):

1. The compression ratio of air-standard Otto cycle is 8' At the beginning of the compression stroke the pressure is 1 bar and the temperature is 17°C .The heat of 800 kJ/kg is added during the constant volume process' Determine: a, The pressure and temperature at each corner of the cycle. (P_2=18.38bar; T_2=666.245K; P_3=49.118bar; T_3=1780.45K; P_4=2.672bar; T_4=774.986K).
b. The thermal efficiency; (56.47%)

2- An engine operates on the theoretic al diesel cycle with a compression ratio of 15. The heat of 1300 kJ/kg is added at constant pressure for 10'% of the stroke volume. The pressure and temperature of the air at the beginning of compression are 100 kPa and 27 °C. Determine,
(a) The cut-off ratio,(2.4) (b) The pressure and temperature at the end of each process, (P_2=4431.265KPa; T_2=886.253K..); (c) The thermal efficiency of the cycle,(58.47%) (d) the output power from the engine if the mass flow rate equal 0.15 kg/s; (114.5KW).

3- An air-standard Dual cycle operates with a compression ratio of 14. The conditions at the beginning of compression are 100 kPa and 300 K. The maximum temperature in the cycle is 2200 K and the heat added at constant volume is twice the heat added at constant pressure. Determined, (a) The pressure, temperature, and specific volume at each corner of the cycle, (P_2=4023.271KPa; T_2=862.129K;v_1=0.861,v_2=0.0615 m^3/kg);(b) The thermal efficiency of the cycle,(64.84%) .