Figure 13.7 shows the air standard cycle, called the *Diesel cycle*, correspondi[ng] to the C.I. engine, as described above. The cycle is composed of:

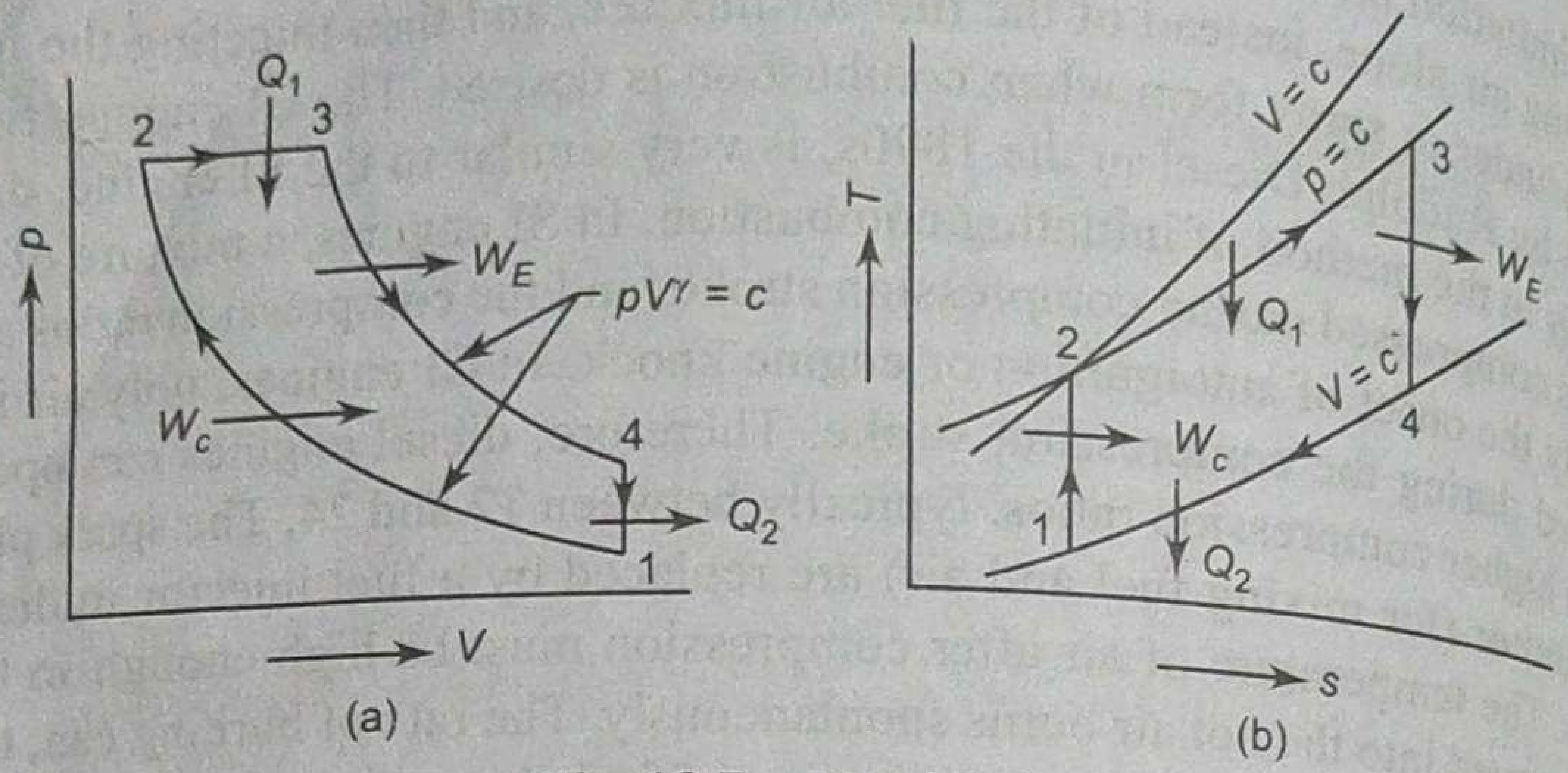


Fig. 13.7 *Diesel Cycle*

Two reversible adiabatics, one reversible isobar, and one reversible isochore.

Air is compressed reversibly and adiabatically in process 1-2. Heat is then adde[d] to it from an external source reversibly at constant pressure in process 2-3. Air the[n] expands reversibly and adiabatically in process 3-4. Heat is rejected reversibly [at] constant volume in process 4-1, and the cycle repeats itself.

For m kg of air in the cylinder, the efficiency analysis of the cycle can be made a[s] given below.

Heat supplied, $$Q_1 = Q_{2-3} = m\, c_p\,(T_3 - T_2)$$

Heat rejected, $$Q_2 = Q_{4-1} = m\, c_v\,(T_4 - T_1)$$

Efficiency $$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{mc_v(T_4 - T_1)}{mc_p(T_3 - T_2)}$$

$\therefore$ $$\eta = 1 - \frac{T_4 - T_1}{\gamma(T_3 - T_2)} \qquad (13.8)$$

The efficiency may be expressed in terms of any two of the following three ratios

Compression ratio, $$r_k = \frac{V_1}{V_2} = \frac{v_1}{v_2}$$

Expansion ratio, $$r_e = \frac{V_4}{V_3} = \frac{v_4}{v_3}$$

Cut-off ratio, $$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

It is seen that

$$r_k = r_e \cdot r_c$$

Process 3-4

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1} = \frac{1}{r_e^{\gamma-1}}$$

$$T_4 = T_3\,\frac{r_c^{\gamma-1}}{r_k^{\gamma-1}}$$

Process 2-3

$$\frac{T_2}{T_3} = \frac{p_2 v_2}{p_3 v_3} = \frac{v_2}{v_3} = \frac{1}{r_c}$$

$$\therefore \quad T_2 = T_3 \cdot \frac{1}{r_c}$$

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

Process 1-2

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma-1} = \frac{1}{r_k^{\gamma-1}}$$

$$\therefore \quad T_1 = T_2 \cdot \frac{1}{r_k^{\gamma-1}} = \frac{T_3}{r_c} \cdot \frac{1}{r_k^{\gamma-1}}$$

Substituting the values of T_1, T_2 and T_4 in the expression of efficiency (Eq. 13.8)

$$\eta = 1 - \frac{T_3 \cdot \frac{r_c^{\gamma-1}}{r_k^{\gamma-1}} - \frac{T_3}{r_c} \frac{1}{r_k^{\gamma-1}}}{\gamma\left(T_3 - T_3 \cdot \frac{1}{r_c}\right)}$$

$$\therefore \quad \eta_{\text{Diesel}} = 1 - \frac{1}{\gamma} \cdot \frac{1}{r_k^{\gamma-1}} \cdot \frac{r_c^{\gamma} - 1}{r_c - 1} \qquad (13.9)$$

As $r_c > 1$, $\frac{1}{\gamma}\left(\frac{r_c^{\gamma} - 1}{r_c - 1}\right)$ is also greater than unity. Therefore, the efficiency of the Diesel cycle is less than that of the Otto cycle for the same compression ratio.

13.8 LIMITED PRESSURE CYCLE, MIXED CYCLE OR DUAL CYCLE

The air standard Diesel cycle does not simulate exactly the pressure-volume variation in an actual compression ignition engine, where the fuel injection is started before the end of compression stroke. A closer approximation is the limited pressure cycle in which some part of heat is added to air at constant volume, and the remainder at constant pressure.

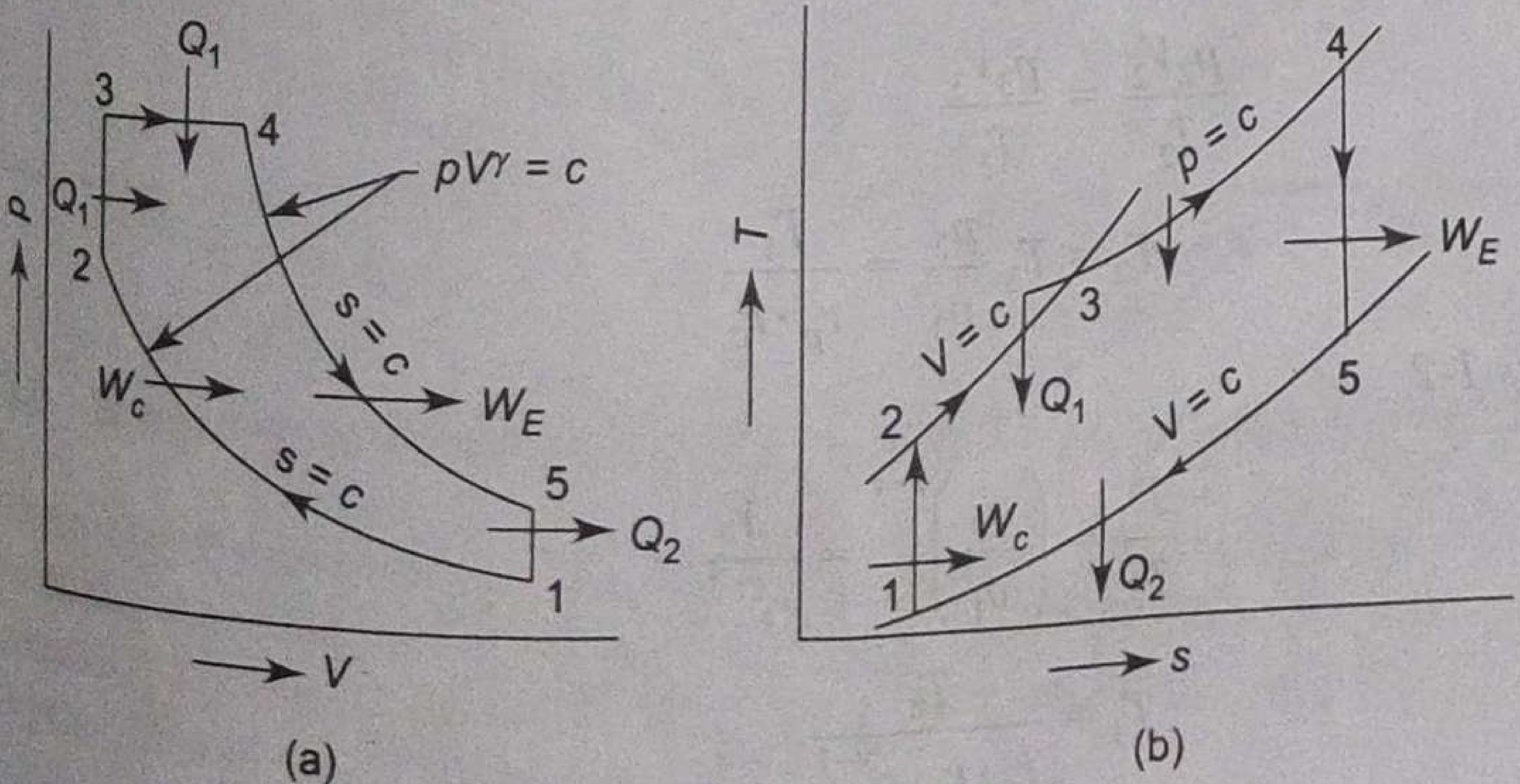


Fig. 13.8 *Limited Pressure Cycle. Mixed Cycle or Dual Cycle*

Process 4-5

$$\frac{T_5}{T_4} = \left(\frac{v_4}{v_5}\right)^{\gamma-1} = \frac{1}{r_e^{\gamma-1}}$$

$$\therefore \quad T_5 = T_4 \cdot \frac{r_c^{\gamma-1}}{r_k^{\gamma-1}}$$

Substituting the values of T_1, T_2, T_3, and T_5 in the expression of efficiency (Eq. 13.8).

$$\eta = 1 - \frac{T_4 \cdot \frac{r_c^{\gamma-1}}{r_k^{\gamma-1}} - \frac{T_4}{r_p \cdot r_c \cdot r_k^{\gamma-1}}}{\left(\frac{T_4}{r_c} - \frac{T_4}{r_p \cdot r_c}\right) + \gamma\left(T_4 - \frac{T_4}{r_c}\right)}$$

$$\therefore \quad \eta_{\text{Dual}} = 1 - \frac{1}{r_k^{\gamma-1}} \frac{r_p \cdot r_c^{\gamma} - 1}{r_p - 1 + \gamma r_p (r_c - 1)} \tag{13.11}$$

13.9 COMPARISON OF OTTO, DIESEL, AND DUAL CYCLES

The three cycles can be compared on the basis of either the same compression ratio or the same maximum pressure and temperature.

Figure 13.9 shows the comparison of Otto, Diesel, and Dual cycles for the same compression ratio and heat rejection. Here

1-2-6-5 —Otto cycle
1-2-7-5 —Diesel cycle
1-2-3-4-5 —Dual cycle

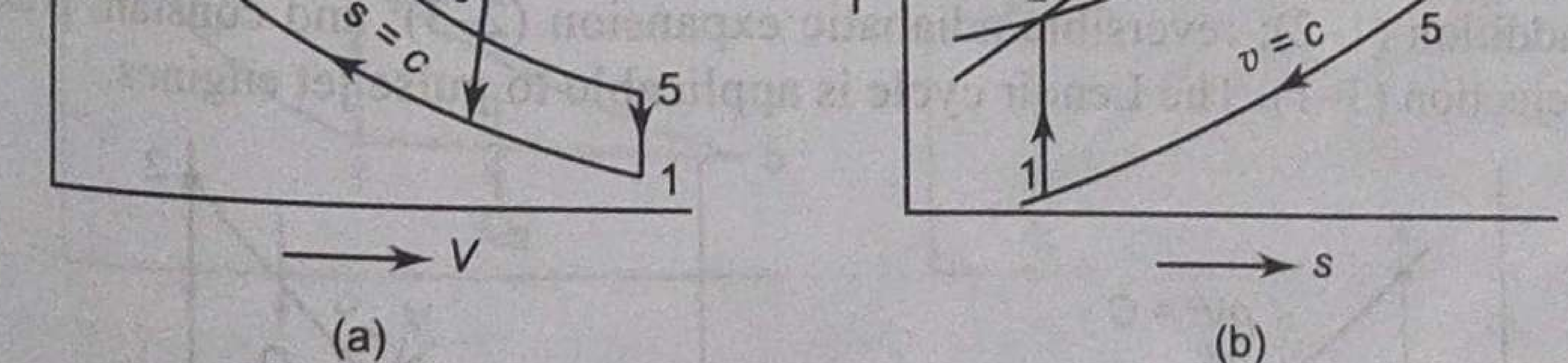


Fig. 13.9 *Comparison of Otto, Diesel and Dual Cycles for the Same Compression Ratio*

For the same Q_2, the higher the Q_1, the higher is the cycle efficiency. In the T-s diagram, the area under 2-6 represents Q_1 for the Otto cycle, the area under 2-7 represents Q_1 for the Diesel cycle, and the area under 2-3-4 represents Q_1 for the Dual cycle. Therefore, for the same r_k and Q_2

$$\eta_{otto} > \eta_{Dual} > \eta_{Diesel}$$

Figure 13.10 shows a comparison of the three air standard cycles for the same maximum pressure and temperature (state 4), the heat rejection being also the same. Here

1–6–4–5 —Otto cycle
1–7–4–5 —Diesel cycle
1–2–3–4–5 —Dual cycle

Q_1 is represented by the area under 6-4 for the Otto cycle, by the area under 7-4 for the Diesel cycle and by the area under 2-3-4 for the Dual cycle in the T-s plot, Q_2 being the same.

$$\therefore \qquad \eta_{Diesel} > \eta_{dual} > \eta_{otto}$$

This comparison is of greater significance, since the Diesel cycle would definitely have a higher compression ratio than the Otto cycle.

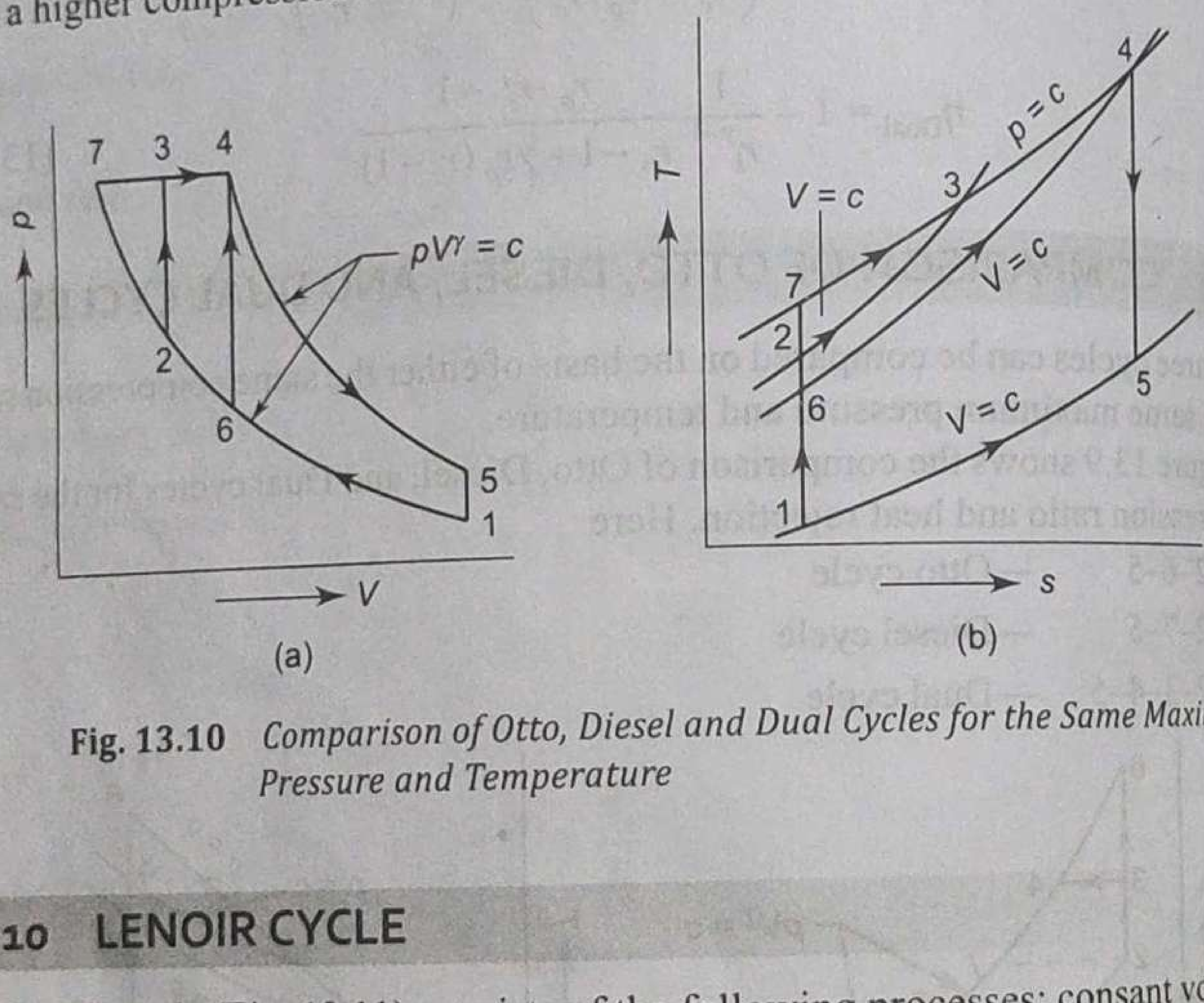


Fig. 13.10 *Comparison of Otto, Diesel and Dual Cycles for the Same Maximum Pressure and Temperature*

13.10 LENOIR CYCLE

The Lenoir cycle (Fig. 13.11) consists of the following processes: consant volume heat addition (1–2); reversible adiabatic expansion (2–3); and constant pressure heat rejection (3–1). The Lenoir cycle is applicable to pulse jet engines.

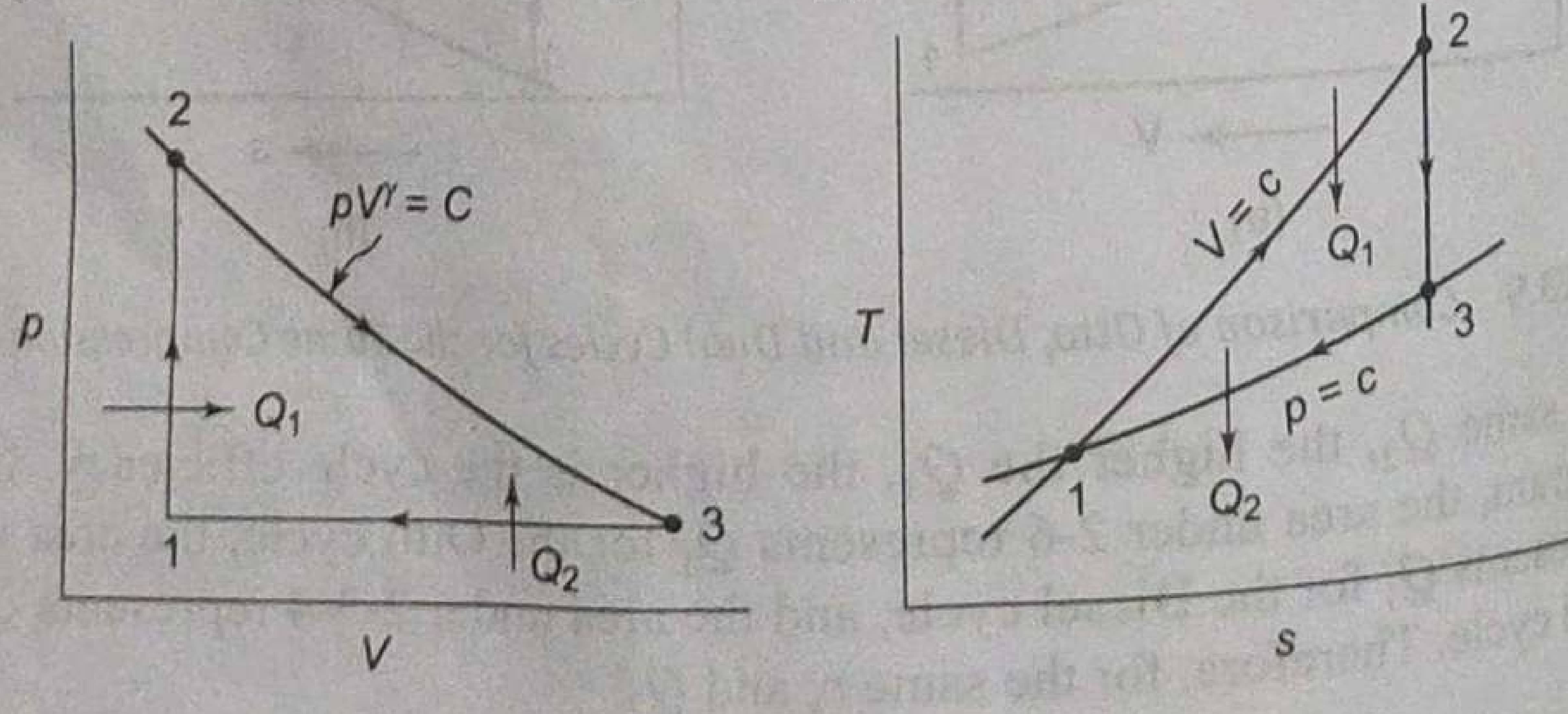
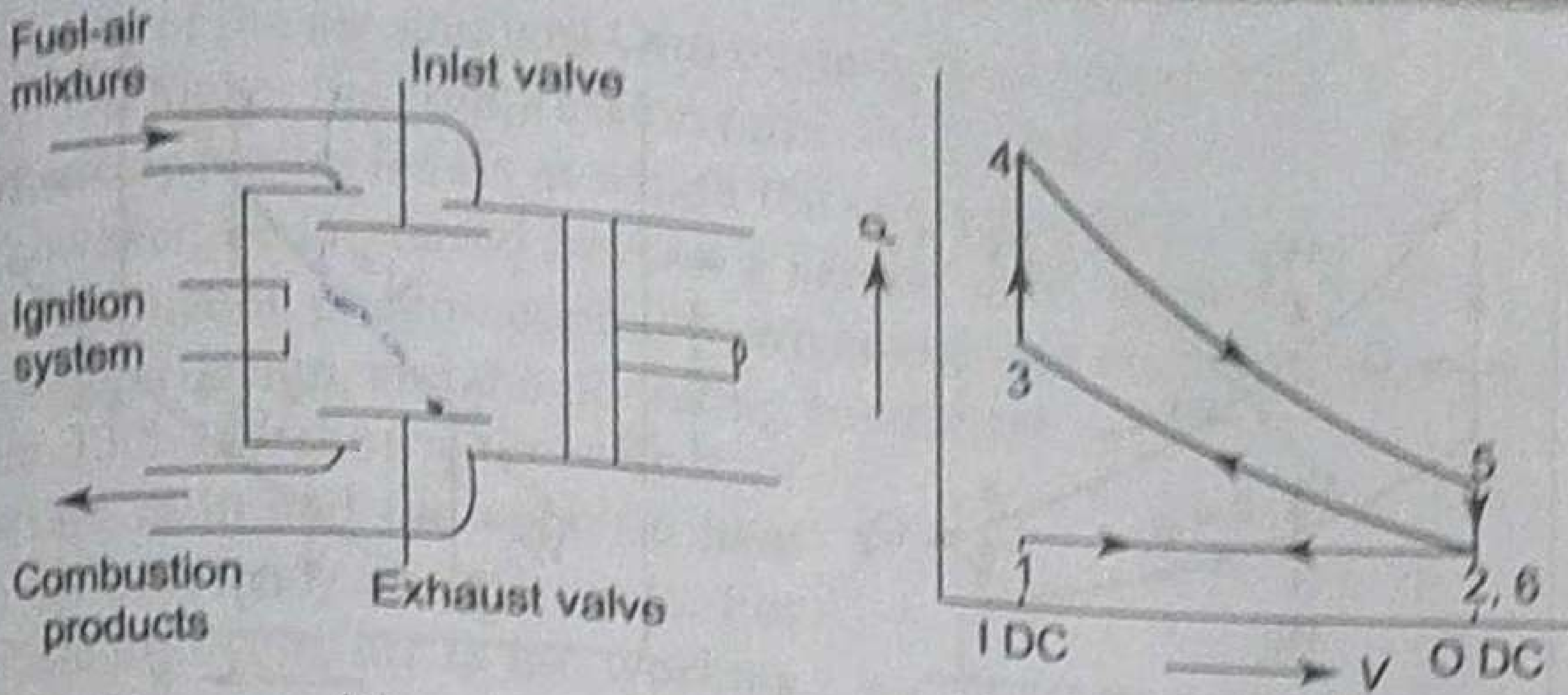


Fig. 13.11 *Lenoir Cycle*



(a)

(b)

Fig. 13.5 *(a) S.I. Engine (Horizontal) (b) Indicator Diagram*

Process 1-2, Intake. The inlet valve is open, the piston moves to the right, admitting fuel-air mixture into the cylinder at constant pressure.

Process 2-3, Compression. Both the valves are closed, the piston compresses the combustible mixture to the minimum volume.

Process 3-4, Combustion. The mixture is then ignited by means of a spark, combustion takes place, and there is an increase in temperature and pressure.

Process 4-5, Expansion. The products of combustion do work on the piston which moves to the right, and the pressure and temperature of the gases decrease.

Process 5-6, Blow-down. The exhaust valve opens, and the pressure drops to the initial pressure.

Process 6-1, Exhaust. With the exhaust valve open, the piston moves inwards to expel the combustion products from the cylinder at constant pressure.

The series of processes as described above constitute a *mechanical cycle*, and not a thermodynamic cycle. The cycle is completed in four strokes of the piston.

Figure 13.5 (c) shows the air standard cycle (Otto cycle) corresponding to the above engine. It consists of: Two reversible adiabatics, one reversible isobar, and one reversible isochore.

Air is compressed in process 1-2 reversibly and adiabatically. Heat is then added to air reversibly at constant volume in process 2-3. Work is done by air in expanding reversibly and adiabatically in process 3-4. Heat is then rejected by air reversibly at constant volume in process 4-1, and the system (air) comes back to its initial state. Heat transfer processes have been substituted for the combustion and blow-down processes of the engine. The intake and exhaust processes of the engine cancel each other.

Let m be the fixed mass of air undergoing the cycle of operations as described above.

$$\text{Heat supplied } Q_1 = Q_{2-3} = mc_v\,(T_3 - T_2)$$

$$\text{Heat rejected } Q_2 = Q_{4-1} = mc_v\,(T_4 - T_1)$$

$$\text{Efficiency} \quad \eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{mc_v(T_4 - T_1)}{mc_v(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2} \tag{13.4}$$

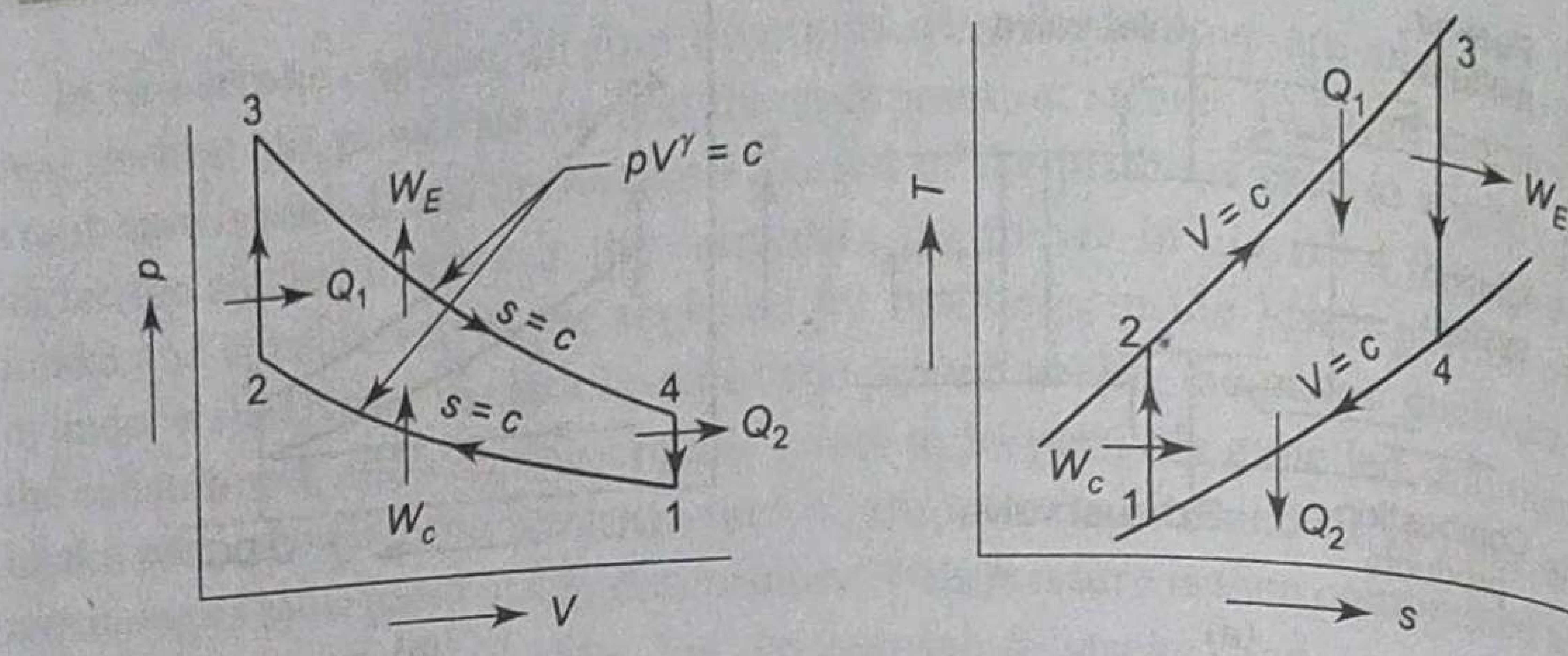


Fig. 13.5 *(c) Otto Cycle*

Process 1-2, $$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

Process 3-4, $$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

$\therefore$ $$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

or $$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$

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

$\therefore$ $$\frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma-1}$$

$\therefore$ From Eq. (13.4), $\eta = 1 - \left(\frac{v_2}{v_1}\right)^{\gamma-1}$

or $$\eta_{\text{otto}} = 1 - \frac{1}{r_k^{\gamma-1}} \quad (13.5$$

where r_k is called the compression ratio and given by

$$r_k = \frac{\text{Volume at the beginning of compression}}{\text{Volume at the end of compression}}$$

$$= \frac{V_1}{V_2} = \frac{v_1}{v_2}$$