4.1 Carnot Cycle :

A Carnot gas cycle operating in a given temperature range is shown in the T-s diagram in Fig. 4.1(a). One way to carry out the processes of this cycle is through the use of steady-state, steady-flow devices as shown in Fig. 4.1(b). The isentropic expansion process 2-3 and the isentropic compression process 4-1 can be simulated quite well by a well-designed turbine and compressor respectively, but the isothermal expansion process 1-2 and the isothermal compression process 3-4 are most difficult to achieve. Because of these difficulties, a steady-flow Carnot gas cycle is not practical.

The Carnot gas cycle could also be achieved in a cylinder-piston apparatus (a reciprocating engine) as shown in Fig. 4.2(b). The Carnot cycle on the p-v diagram is as shown in Fig. 4.2(a), in which processes 1-2 and 3-4 are isothermal while processes 2-3 and 4-1 are isentropic. We know that the Carnot cycle efficiency is given by the expression.

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

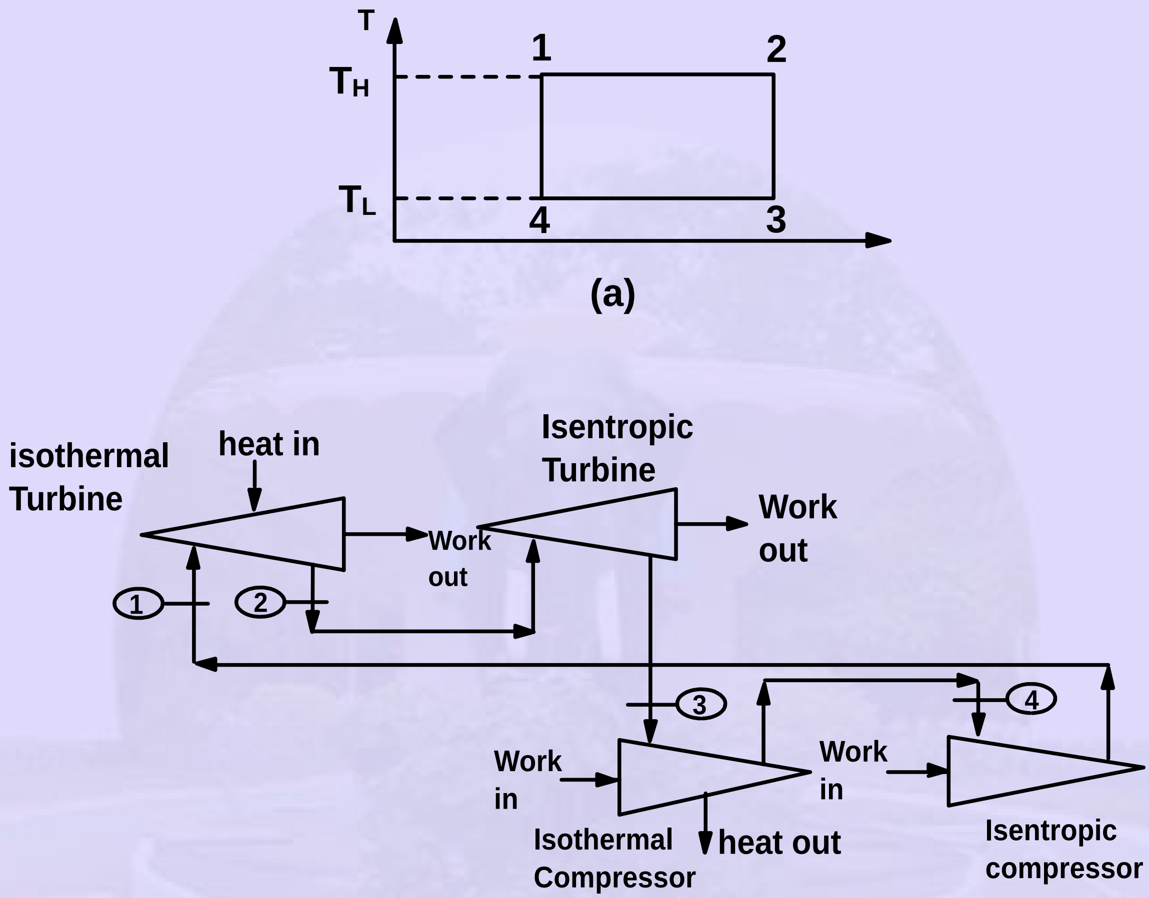

Fig.4.1. Steady flow Carnot engine

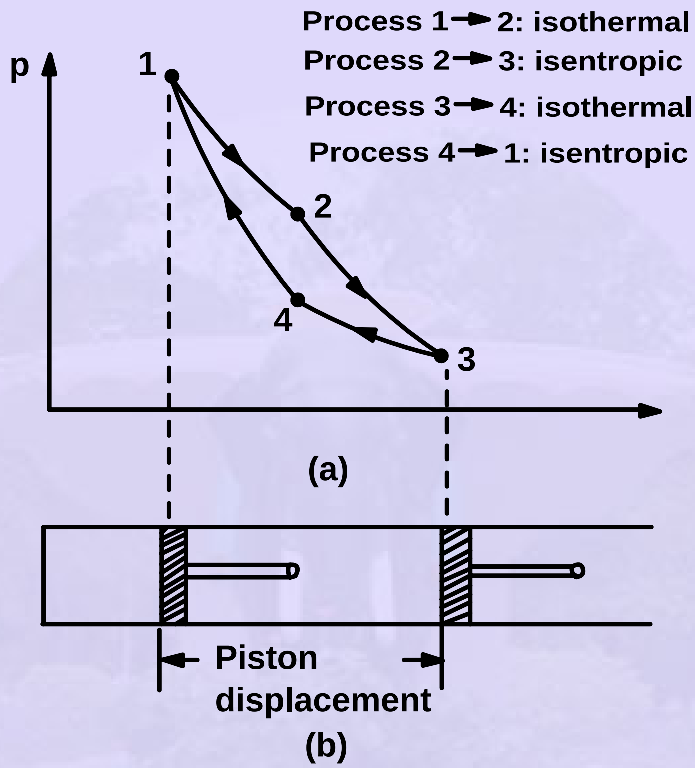

Fig.4.2. Reciprocating Carnot engine

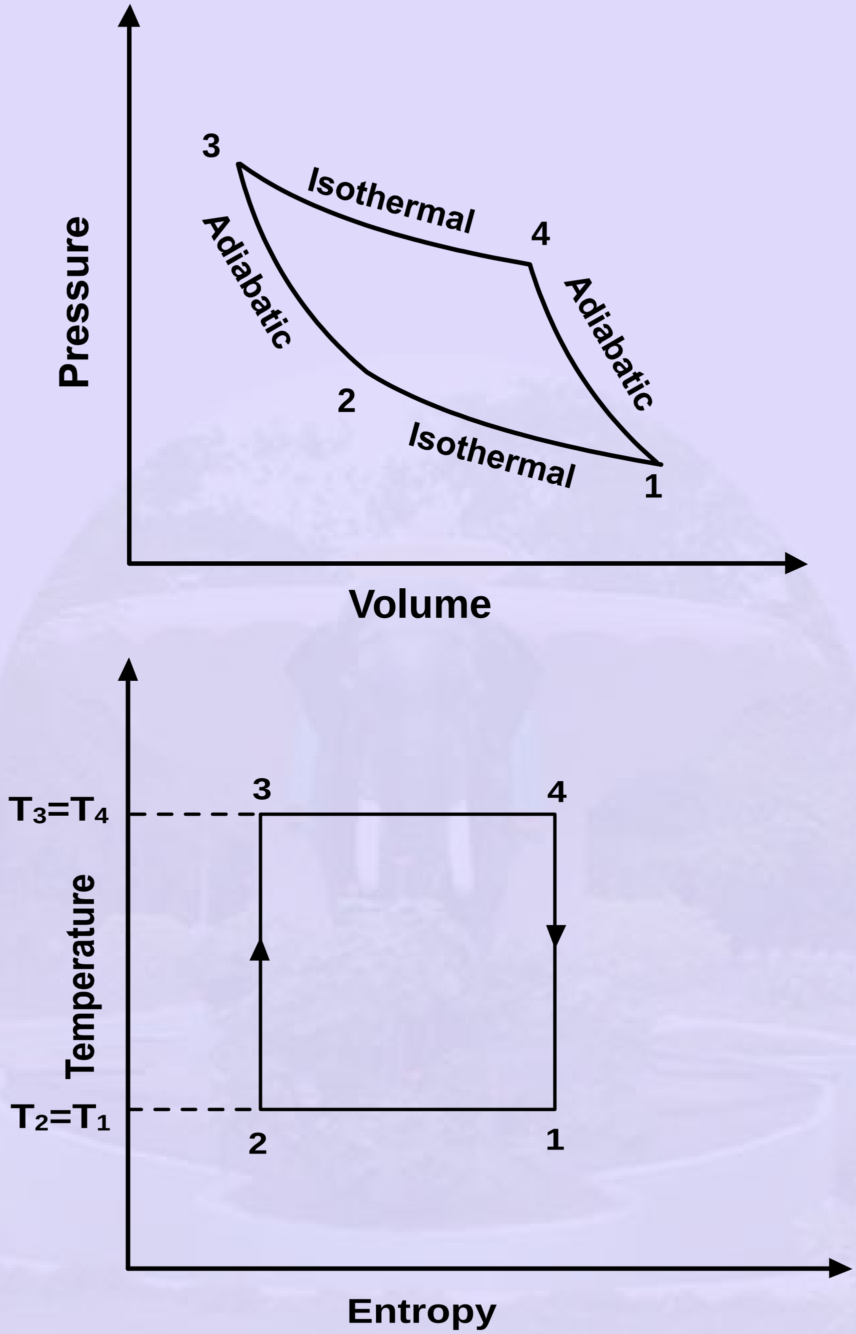

Fig.4.3. Carnot cycle on p-v and T-s diagrams

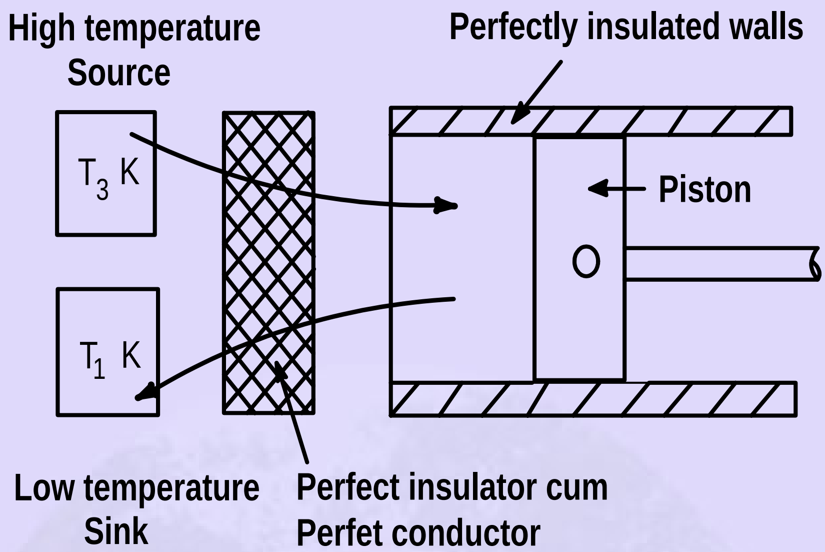

Fig.4.4. Working of Carnot engine

Since the working fluid is an ideal gas with constant specific heats, we have, for the isentropic process,

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} \quad ; \quad \frac{T_2}{T_3} = \left(\frac{V_3}{V_3}\right)^{\gamma-1}$$

Now, $T_1 = T_2$ and $T_4 = T_3$, therefore

$$\frac{v_4}{v_1} = \frac{v_3}{v_2} = r = \text{compression or expansion ratio}$$

Carnot cycle efficiency may be written as,

$$\eta_{th} = 1 - \frac{1}{r^{\gamma - 1}}$$

From the above equation, it can be observed that the Carnot cycle efficiency increases as ‘r’ increases. This implies that the high thermal efficiency of a Carnot cycle is obtained at the expense of large piston displacement. Also, for isentropic processes we have,

$$\frac{T_1}{T_4} = \left(\frac{p_1}{p_4}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{and} \quad \frac{T_2}{T_3} = \left(\frac{p_2}{p_3}\right)^{\frac{\gamma-1}{\gamma}}$$

Since, $T_1 = T_2$ and $T_4 = T_3$, we have

$$\frac{p_1}{p_4} = \frac{p_2}{p_3} = r_p = \text{pressure ratio}$$

Therefore, Carnot cycle efficiency may be written as,

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{\gamma - 1}{\gamma}}}$$

From the above equation, it can be observed that, the Carnot cycle efficiency can be increased by increasing the pressure ratio. This means that Carnot cycle should be operated at high peak pressure to obtain large efficiency.