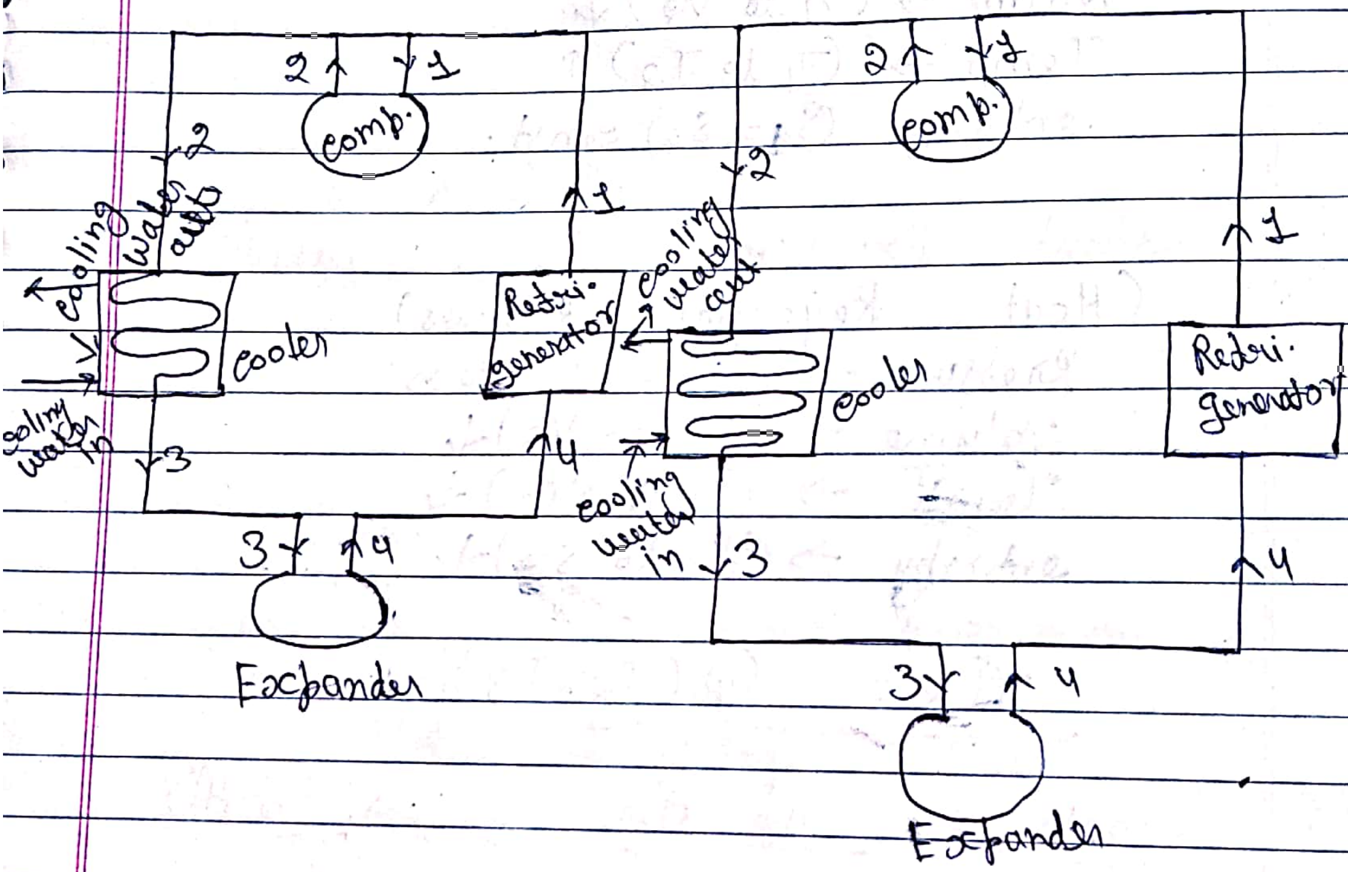
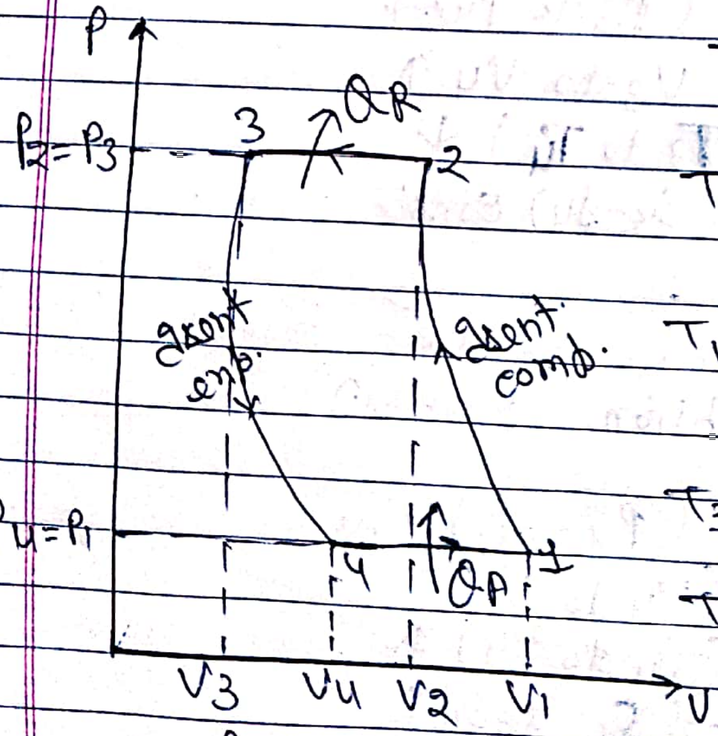
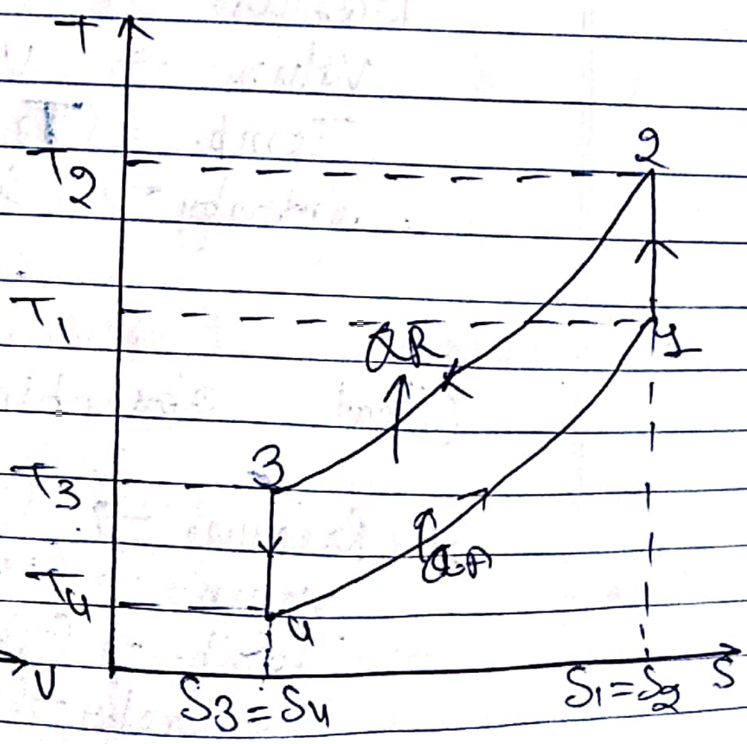
Answer




P-V diagram




T-S-diagram

a) **Isentropic compression process :- (1-2) :-**

Pressure → ($P_1$ to $P_2$) ↑
Volume → ($V_1$ to $V_2$) ↓
Temp → ($T_1$ to $T_2$) ↑
entropy ($S_1 = S_2$) const.

b) **Constant Pressure cooling process :- (2-3) :-**
(Heat Rejection Process)
Pressure → ($P_2 = P_3$) cons.
volume → ($V_2$ to $V_3$) ↓
Temp → ($T_2$ to $T_3$) ↓
entropy → ($S_2$ to $S_3$) ↓

$$Q_R = C_p (T_2 - T_3)$$

c) **Isentropic Expansion Process :- (3-4) :-**

Pressure → ($P_3$ to $P_4$) ↓
Volume → $V_3$ to $V_4$ ↑
Temp. → ($T_3$ to $T_4$) ↓
entropy → ($S_3$-$S_4$) cons.

d) **Constant Pressure Heating Process :- (4-1) :-**
(Heat absorption Process)

Pressure → ($P_4 = P_1$) cons
volume → ($V_4$ to $V_1$) ↑
Temp. → ($T_4$ to $T_1$) ↑
entropy → ($S_4$ to $S_1$) ↑

$$Q_A = C_p (T_1 - T_4)$$

work done / kg of Air = $Q_R - Q_A$

$$COP = \frac{Q_A}{W} = \frac{Q_A}{Q_R - Q_A}$$

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

$$COP = \frac{T_4\left(\frac{T_1}{T_4} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_1}{T_4} - 1\right)} \quad \text{——} (1)$$

thus during isentropic compression (1-2)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

isent. expansion 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$\{P_2 = P_3\}$ and $\{P_1 = P_4\}$

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

from eqn (1) then we have.

$$COP = \frac{T_4\left(\frac{T_2}{T_3} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_2}{T_3} - 1\right)}$$

$$COP = \frac{T_4\left(\frac{T_2}{T_3}-1\right)}{(T_3-T_4)\left(\frac{T_2}{T_3}-1\right)}$$

$$COP = \frac{T_4}{T_3-T_4}$$

$$COP = \frac{T_4}{T_4\left(\frac{T_3}{T_4}-1\right)} \Rightarrow \frac{1}{\left(\frac{T_3}{T_4}-1\right)}$$

$$COP = \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}-1}$$

where $\frac{P_3}{P_4} = r_p$

$$COP = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}-1}$$

$$\boxed{COP = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}-1}}$$

Sometime, compression and expansion take place according to the law $\boxed{PV^n = \text{constant}}$