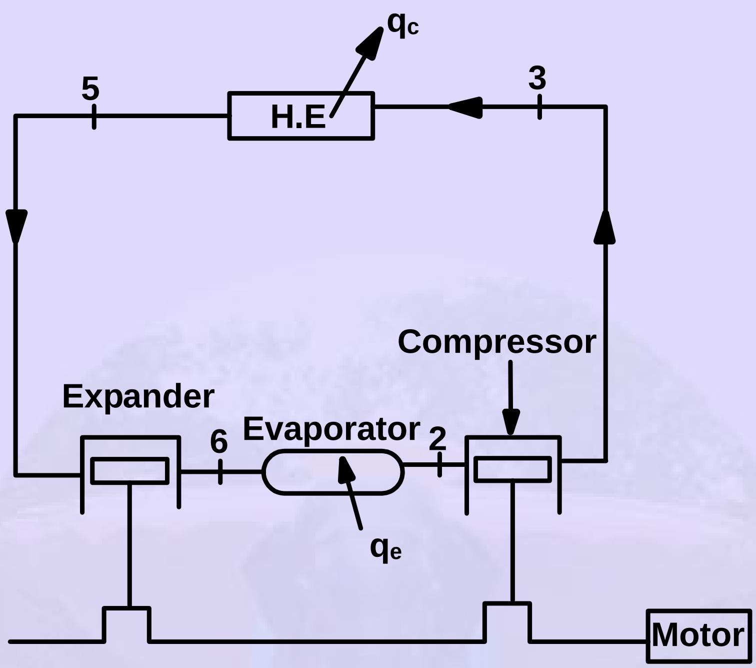
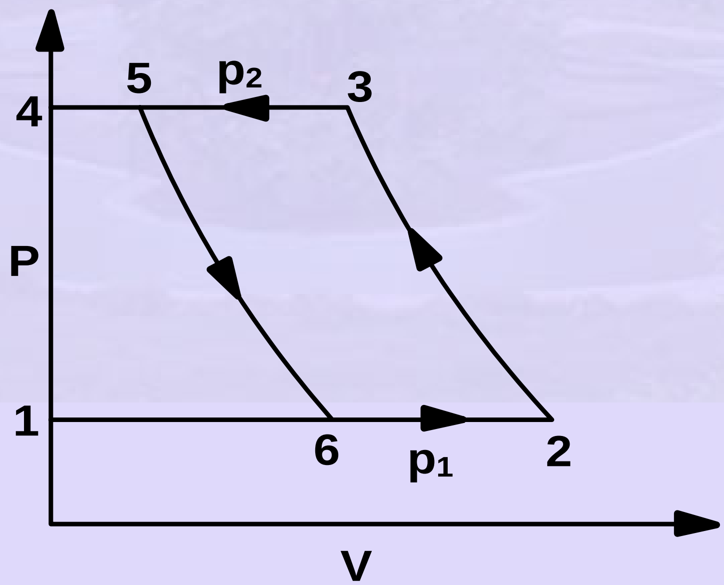
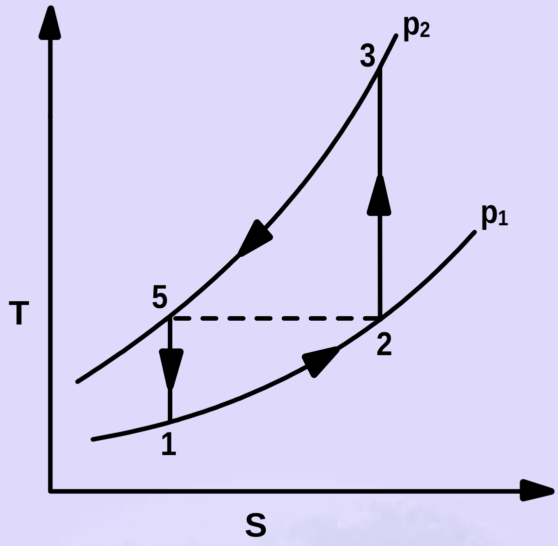
6.3 Air Refrigeration System And Bell-Coleman Cycle Or Reversed Brayton Cycle:



6.3 (a) Air refrigeration system



6.3 (b) Air refrigeration system



6.3 (c) Air refrigeration system

The components of the air refrigeration system are shown in Fig.6.3(a). In this system, air is taken into the compressor from atmosphere and compressed. The hot compressed air is cooled in heat exchanger upto the atmospheric temperature (in ideal conditions). The cooled air is then expanded in an expander. The temperature of the air coming out from the expander is below the atmospheric temperature due to isentropic expansion. The low temperature air coming out from the expander enters into the evaporator and absorbs the heat. The cycle is repeated again. The working of air-refrigeration cycle is represented on p-v and T-s diagrams in Fig.6.3(b) and (c).

Process 1-2 represents the suction of air into the compressor. Process 2-3 represents the isentropic compression of air by the compressor. Process 3-5 represents the discharge of high pressure air from the compressor into the heat exchanger. The reduction in volume of air from v_3 to v_5 is due to the cooling of air in the heat exchanger. Process 5-6 represents the isentropic expansion of air in the expander. Process 6-2 represents the absorption of heat from the evaporator at constant pressure.

6.3.1. Analysis of Bell-Coleman Cycle:

The air refrigeration system works on Bell-Coleman cycle.

Assumptions:

1) *The compression and expansion processes are reversible adiabatic processes.*
2) *There is a perfect inter-cooling in the heat exchanger.*
3) *There are no pressure losses in the system.*

$$\text{COP} = \frac{\text{Net refrigeration effect}}{\text{Net work supplied}}$$

Work done per kg of air for the isentropic compression process 2-3 is given by,

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

Work developed per kg of air for the isentropic expansion process 5-6 is given by,

$$W_E = C_p(T_5 - T_6)$$

$$\text{Net work required} = W_{net} = (W_C - W_E) = C_p(T_3 - T_2) - C_p(T_5 - T_6)$$

Net refrigerating effect per kg of air is given by,

$$R_{net} = C_p(T_2 - T_6)$$

$$\text{COP} = \frac{R_{net}}{W_{net}} = \frac{C_p(T_2 - T_6)}{C_p\{(T_3 - T_2) - (T_5 - T_6)\}}$$

For perfect inter-cooling, the required condition is $T_5 = T_2$

$$\text{COP} = \frac{(T_2 - T_6)}{(T_3 - T_2) - (T_2 - T_6)}$$

$$= \frac{1}{\dfrac{(T_3 - T_2)}{(T_2 - T_6)} - 1} \text{ (for isentropic process)}$$

$$= \frac{1}{\dfrac{T_3(1 - T_2/T_3)}{T_2(1 - T_6/T_2)} - 1}$$

For isentropic compression process 2-3 and for expansion process 5-6, we have,

$$\frac{T_3}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} \text{ and } \frac{T_5}{T_6} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Therefore, $\frac{T_3}{T_2} = \frac{T_5}{T_6}$ or $\frac{T_6}{T_5} = \frac{T_2}{T_3} \quad \because (T_5 = T_2)$

$$COP = \frac{T_2}{T_3 - T_2}$$

Advantages:

a) Air is a cheaper refrigerant and available easily compared to other refrigerants.

b) There is no danger of fire or toxic effects due to leakage.

c) The total weight of the system per ton of refrigerating capacity is less.

Disadvantages:

(a) The quantity of air required per ton refrigerating capacity is far greater than other systems.

(b) The COP is low and hence maintenance cost is high.

(c) The danger of frosting at the expander valves is more as the air taken into the system always contains moisture.

Work done during Compression and Expansion Processes (for polytropic processes) (Refer P-V-diagram) (For problem solving)

$$
\begin{aligned}
W_C &= P_3V_3 + \frac{P_3V_3 - P_2V_2}{n-1} - P_2V_2 \\
&= \left(P_3V_3 - P_2V_2\right) + \frac{\left(P_3V_3 - P_2V_2\right)}{n-1} \\
&= \frac{n}{n-1}\left(P_3V_3 - P_2V_2\right)
\end{aligned}
$$