MECHANICAL ENGINEERING DEPARTMENT

LECTURE NOTES

FOR

THE SUBJECT

REFRIGERATION AND AIR CONDITIONING

5^{TH} SEMESTER

By

SUNITA SAMAL

SR. LECT (MECHANICAL)

Senior Lecturer
Mechanical Engg. Dept.
BOSE, Cuttack

Aire

Refreigereation cycle.

Senior Lecturer
Mechanical Engg. D...

Definition

- Refrigeration may be defined as the process of removing heat from a substance under controlled conditions.
- It also includes the process of reducing and maintaining temperature of a body below the general temperature of its surroundings.

Unit of Refrigeration

Unit of refrigeration is expressed in terms of "tonne of refrigeration" or TR

A TR is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (1000 kg) of ice from and at 0°c in 24 hours.

Since latent heat of ice is 335 kJ/kg.

$$1\ TR = 1000 \times 335\ kJ \text{ in } 24 \text{ hrs}$$

$$= \frac{1000 \times 335}{24 \times 60} = 232.6\ kJ/min$$

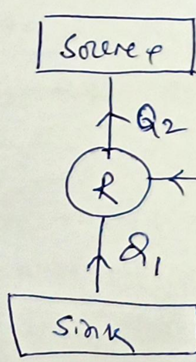
Actual Practice

$$1\ TR = 210\ kJ/min \text{ or } 3.5\ kW$$

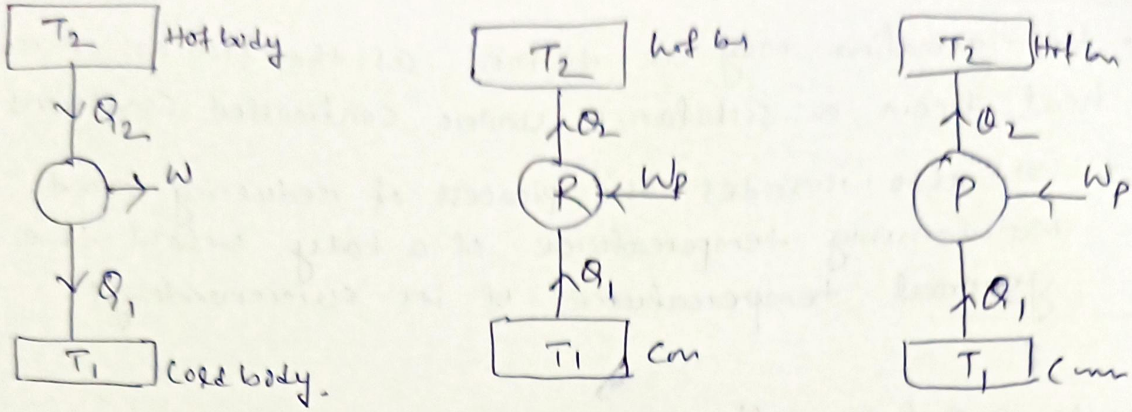
C.O.P

$$C.O.P = \frac{\text{Heat extracted}}{\text{work done.}}$$

$$= \frac{Q_1}{W}$$



Difference Between Heat engine, Refrigerator and Heat p



$$(COP)_{HE} \text{ or } \eta_{HE} = \frac{W}{Q_2} = \frac{Q_2 - Q_1}{Q_2}$$

$$(COP)_R = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1}$$

$$(COP)_P = \frac{Q_2}{W} = \frac{Q_2}{Q_2 - Q_1} = 1 + \frac{Q_1}{Q_2 - Q_1}$$

$$= 1 + (COP)_R$$

Air refrigeration cycle

Air refrigeration cycle
- Open
- close.

Sunita Samal.
Senior Lecturer

3 Open and closed aire system of refreigeration.

Open Aire refreigeration cycle.

- In an open aire refreigeration cycle the aire is directly led to the space to be cooled. Allowed to circulate through the cooler and then returned to the compressore to start another cycle. Aire is supplied to refreigeratore at atmospheric pressure.

Disadvantages of open aire refreigeration cycle.

- The size of compressore and expandere should be large as the volume of aire handled by them is large.
- The moisture is regularly carried away by aire circulated through the cooled space. This leads to the formation of frost and clog the line.

Closed ore Dense Aire refreigeration cycle.

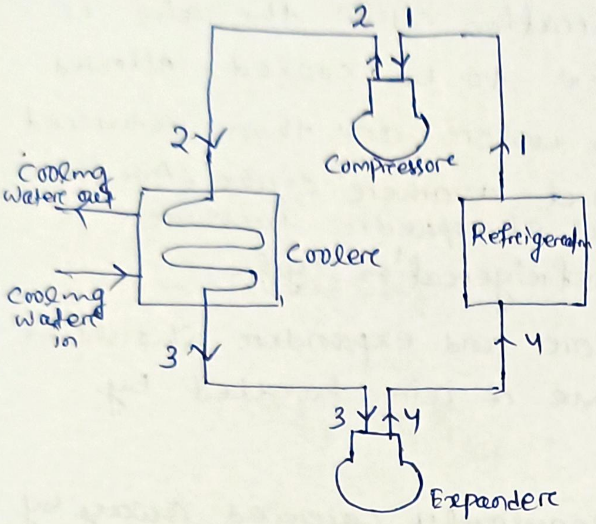
- In this case aire is passed through the pipes and component parts of the system at all times.
- Here aire is used fore absorbing heat from the brine solution and that cooled brine is circulated in to the space to be cooled.

Advantages of closed aire refreigeration cycle.

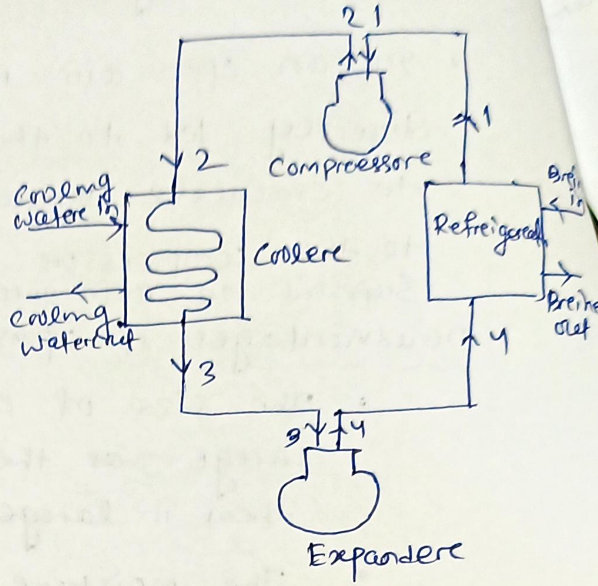
- It can work at a pressure higher than atmosphere pressure.
- Volume of aire handled are smaller thus the size of expandere and compressore will be small.
- The operating pressure ratios can be reduced. Which results higher C.O.P.

Sanita Samal ...

1.3.1 Bell-Coleman cycle. (reversed Brayton or Joule cy...



Open cycle air Bell-coleman refrigerator

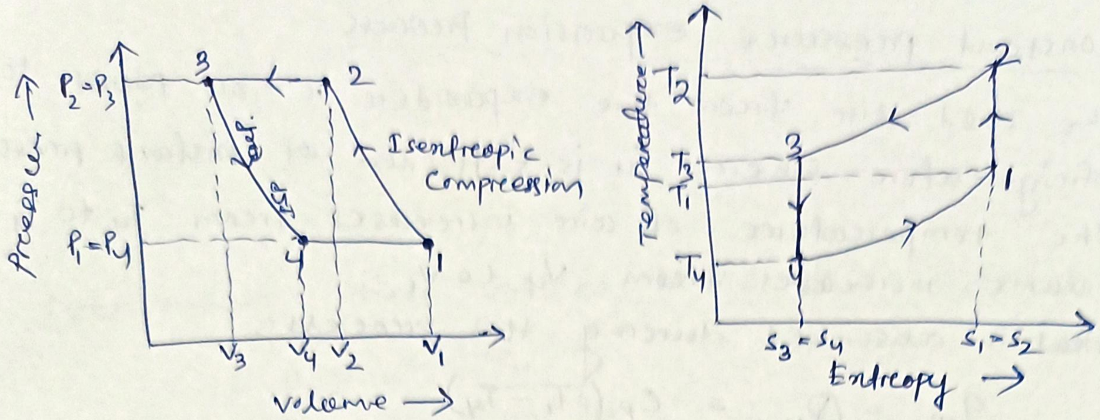


Closed cycle air Bell-coleman refrigerator

- This machine or refrigerator was developed by Bell-Coleman and Light foot by reversing Joule's air cycle
- It was an earliest types of refrigerators used in ships carrying frozen meat.
- It consists of:
  - a compressor
  - a cooler
  - an expander
  - a refrigerator

The cycle is shown on P-V and T-S diagram. At point-1 P_1, V_1 and T_1 are the pressure, volume and temperature of air respectively. The four processes of the cycle are

1. Isentropic compression process (1-2)
2. Constant pressure cooling process (2-3)
3. Isentropic expansion process (3-4)
4. Constant pressure expansion process (4-1)



① Isentropic Compression Process (1-2)

In this process the cold air drawn from the refrigerator is compressed isentropically in the compressor. During compression stroke, both pressure and temperature increases and specific volume of air reduces from V_1 to V_2. No heat is absorbed or rejected by the air

② Constant pressure cooling process (2-3)

The warm air from the compressor is now passed in to the cooler where it is cooled at constant pressure P_3 ($P_3 = P_2$). Temperature reduces from T_2 to T_3. Volume reduces from V_2 to V_3. Heat is rejected during this process.

Heat rejected/kg of air $= Q_{2-3} = q_R = C_P(T_2 - T_3)$

③ Isentropic expansion process (3-4)

The air from the cooler is now expanded isentropically in the expander cylinder from pressure P_3 to P_4. The temperature of air falls from T_3 to T_4. The specific volume of air increases from V_3 to V_4. During this process no heat is absorbed or rejected.

Senior Lecturer

(4) Constant pressure expansion process

The cold air from the expander is now passed to the refrigerator where it is expanded at constant pressure. The temperature of air increases from T_4 to T_1. volume increases from V_4 to V_1.
Heat is absorbed during this process.

$$q_A = Q_{4-1} = C_p(T_1 - T_4)$$

Work done during the cycle per kg of air

$$= \text{Heat rejected} - \text{Heat absorbed}.$$

$$= C_p(T_2 - T_3) - C_p(T_1 - T_4)$$

$$C.O.P = \frac{\text{Heat absorbed}}{\text{Work done}}$$

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

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

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

We know for isentropic compression process 1-2

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

Similarly for isentropic expansion process 3-4

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

As $P_2 = P_3$ and $P_1 = P_4$

Senior Lecturer
Mechanical Engg.

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

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

Substituting these values in the above equation.

$$C.O.P. = \frac{T_4}{T_3 - T_4}$$

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

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

$$= \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{r-1}{r}} - 1}$$

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

r_p = Compression or Expansion ratio

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

If the compression and expansion process take place according to the law PV^n = constant then

C.O.P will be ~~$\frac{...}{n-1}$~~

Work done by compressor during the process 1-2 per kg of air

$$W_C = \frac{n}{n-1}(P_2V_2 - P_1V_1)$$

$$= \frac{n}{n-1}(RT_2 - RT_1)$$

$$W_E = \frac{n}{n-1}(P_3V_3 - P_4V_4).$$

$$= \frac{n}{n-1}[RT_3 - RT_4]$$

Senior Lecturer
Mechanical Engg. Dept.
?OSE, Cuttack

Net work done per kg of air in the cycle.

$$w = W_C - W_E$$

$$= \frac{n}{n-1} \times R\left[(T_2 - T_1) - (T_3 - T_4)\right]$$

$$C.O.P = \frac{\text{Heat absorbed}}{\text{work done}}$$

$$= \frac{q_A}{w}$$

$$= \frac{c_p(T_1 - T_4)}{\frac{n}{n-1} \times R\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

We know $R = C_p - C_v = C_v(\gamma - 1)$

$$C.O.P = \frac{C_p(T_1 - T_4)}{\frac{n}{n-1} \times C_v(\gamma-1)\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

$$= \frac{\gamma(T_1 - T_4)}{\frac{n}{n-1} \times (\gamma-1)\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

$$= \frac{T_1 - T_4}{\frac{n}{n-1} \times \frac{\gamma-1}{\gamma}\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

$$= \frac{T_1 - T_4}{\frac{n}{n-1} \times \frac{\gamma-1}{\gamma}\left[(T_2 - T_3) - (T_1 - T_4)\right]}$$

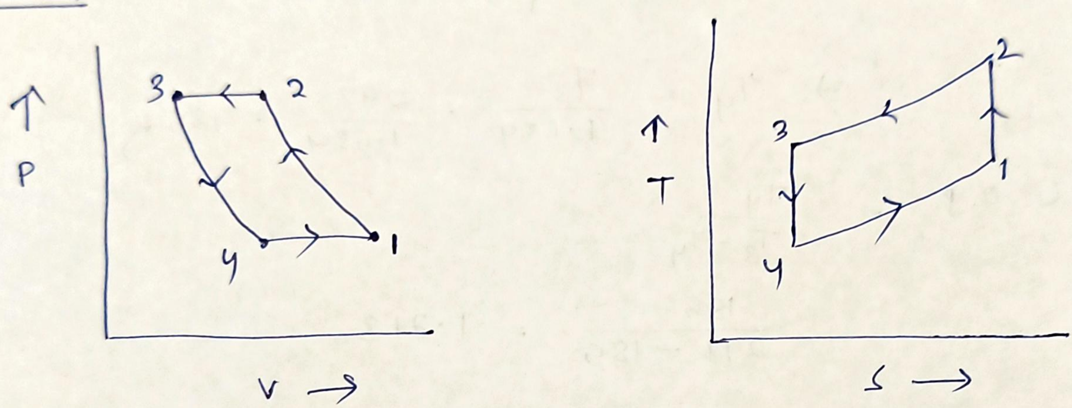
If $n = \gamma$ then

$$C.O.P = \frac{T_1 - T_4}{(T_2 - T_3) - (T_1 - T_4)}$$

Numericals

Q.1 In a refrigerator plant working on Bell-coleman cycle, air is compressed to 5 bar from 1 bar. Its initial temperature is 10°C. After compression the air is cooled up to 20°C in a cooler before expanding back to a pressure of 1 bar. Determine the theoretical C.O.P of the plant and net refrigerating effect. Take $C_p = 1.005$ kJ/kgK and $C_v = 0.718$ kJ/kgK.

Solution



Given

$P_1 = P_4 = 1$ bar

$T_1 = 10°C = 10 + 273 = 283$ K

$T_3 = 20°C = 20 + 273 = 293$ K

$C_p = 1.005$ kJ/kgK

$C_v = 0.718$ kJ/kgK

$$\gamma = \frac{C_p}{C_v} = \frac{1.005}{0.718} = 1.4$$

To Find

$$C.O.P = \frac{T_4}{T_3 - T_4}$$

Refrigerating effect $= C_p (T_1 - T_4)$

Senior Lecturer
Dept.

For isentropic compression 1-2

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

$$= \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$= 1.584$$

For isentropic expansion 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= \left(\frac{5}{1}\right)^{0.286} = 1.584$$

$$\Rightarrow T_4 = \frac{T_3}{1.584} = \frac{293}{1.584} = 185\,K$$

$$C.O.P = \frac{T_4}{T_3 - T_4}$$

$$= \frac{185}{293 - 185} = 1.713$$

$$R.E = c_p (T_1 - T_4)$$

$$= 1.005\,(283 - 185) = 98.5\ \text{kJ/kg}\ \text{Ans}$$