R.A.C

Introduction

Temp.

$$\frac{C}{5} = \frac{F-32}{9}$$

$9x = 5(F-32)$

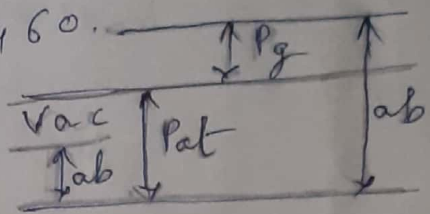
$9x = 5(x-32) = 5x - 160$

$4x = -160, \quad x = -40$

$-40^\circ C = -40^\circ F$

$^\circ K = ^\circ C + 273, \quad ^\circ R = ^\circ F + 460$

Absolute Zero $= -273^\circ C$

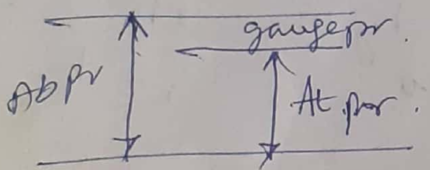


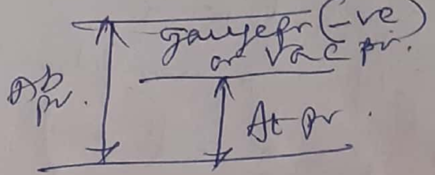
Pr Ab pr = At pr + gauge pr.

For -ve values of Pr. Ab pr = At pr − Vac. pr.

$P_{ab} + P_{vac} = P_a$

$P_{at} - (P_{vac}) = P_{ab}$

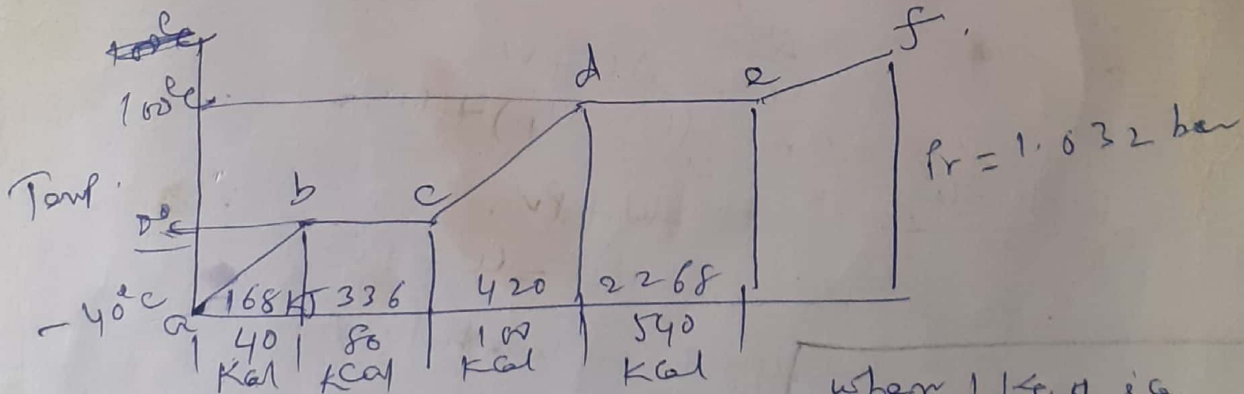




ex 1.2, 1.3. Khurmi.

Heat $Q = m c_p (\Delta T)$

Total heat Total Ht = Sensible ht + latent ht.



ab → SH of ice

bc → latent ht of fusion

cd − SH ~~of vaporization~~

de − LH " of vaporization

ef − super heat

---

when 1 kg of ice changes into water at const temp of 0°C, 334.5 KJ are absorbed from surroundings.

Vapours.

① Sat liq → The heat of liq reaches its max^m value when the liq in saturation condition exists.

Dry Saturated vapour:
The vapour given off by boiling liq is at the same temp as the liq and the vapour is called the saturated vap. (dry vap).

mixture of vap + sat liq = wet sat vap.

dryness fraction of wet sat vap $(x) = \frac{M}{M+m}$.

M = wt of dry vap, m = entrained liq particles.

I st law $E_1 + Q = E_2$.

If work is developed by the system
$Q = (E_2 - E_1) + w$.

Internal energy $U = E - KE - PE$

Stored energy $E = U + KE + PE$
$dE = \Delta U + \Delta KE + \Delta PE$

Closed system $\Delta KE = 0$, $\Delta PE = 0$.
$dE = \Delta U$.

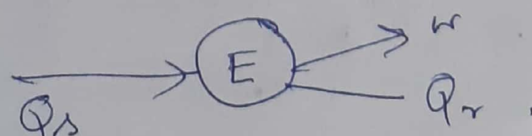
$Q = \Delta U + W$.
$Q = (U_2 - U_1) + W$.

enthalpy $H = U + Pv$.

Per unit mass, $h = u + Pv$.
enthalpy is a useful property.

Joules law. $Q = WJ$.
$J = \frac{Q}{W}$.

2nd law



entropy $ds = \int_1^2 \frac{dQ}{T}$, $W = \int_1^2 P dv$.

$dQ = T \cdot ds$. $dw = P \cdot dv$.

Refgn & 2nd law of Thermodynamics

low Temp to high Temp ..

input of work is essential .

—— x ——

Heat Tr . Conduction, Convection, radiation

Newton's law of Cooling .

Heat Tr from hot body to Cold body is directly proportional to surface area & diff in temps .

Fourier's law of heat Conduction

$$Q \propto KA \frac{dT}{dx} = \frac{KA(T_1 - T_2)}{\Delta x}.$$

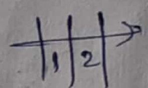
Composite wall

x_1 = Thickness of Matl

K_1 = Thermal Conductivity of Matl.

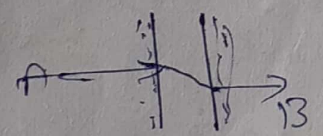
x_2 =

K_2 =



$$Q = \frac{A(T_1 - T_2)}{\Delta x / K} = \frac{A(T_1 - T_3)}{\frac{x_1}{K_1} + \frac{x_2}{K_2}} = \frac{(T_1 - T_3)}{\sum \frac{x}{AK}}.$$

overall heat Tr Coeff
(by Conduction & Convection)



T_A & T_B = Temp of films.

h_A & h_B - Coeffts of h t at films.

U = overall ht

$$Q = UA\Delta T$$

Toper $$U = \frac{1}{\left(\frac{1}{h_A} + \frac{x}{k} + \frac{1}{h_B}\right)}.$$

extended $$U = \frac{1}{\frac{1}{h_A} + \frac{x_1}{K_1} + \frac{x_2}{K_2} \cdots + \frac{1}{h_B}}.$$

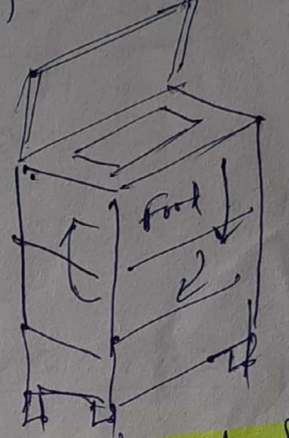
Method of Refgn.

ASRE, American Society of Ref Engrs

ASHRAE – American Society of heating, Refgn & Air conditioning Engrs

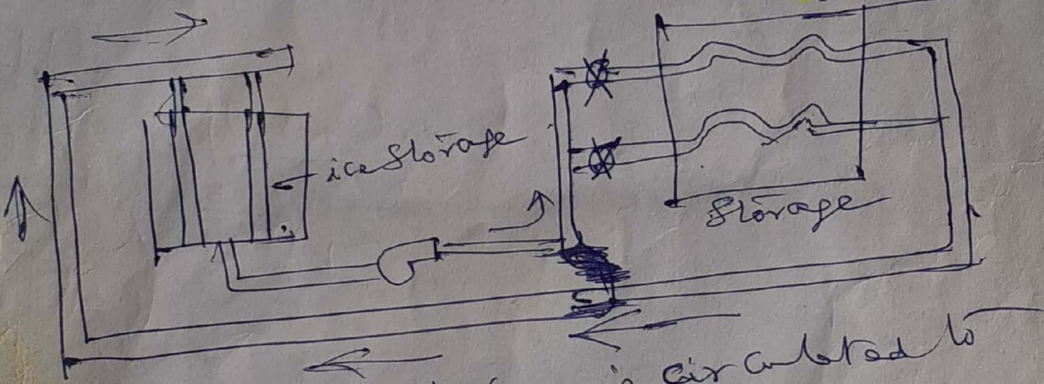
ASRE defines: the Science of providing & maintaining temp below that of surrounding atmosphere.

1) **ice Refrigerator**



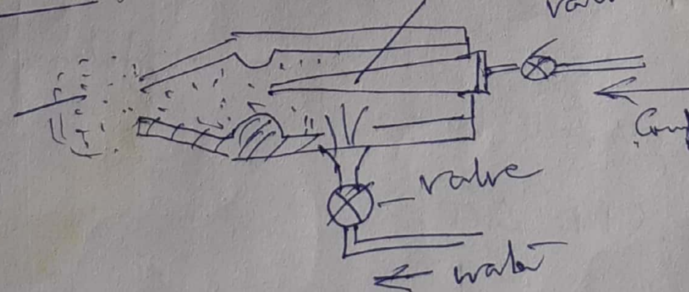
Cold air comes down, hot air goes up. convection currents are developed. Food gets cooled.

Direct system



Ice cools brine & brine is circulated to cool the products. (**indirect Refgn**)

2) **evaporative Refgn**



Heat is absorbed when a liq evaporates or evaporation causes cooling.

(ex:- sweat), desert bag.

Here – water comes out with air as tiny droplets.

If outside air is near freezing, water droplets evaporate & ice is formed. Artificial snow is ... snow can be made at 2°C

unit of Refrgn

$$\frac{2000\ lb \times 144\ BTU/lb}{24} = 12000\ BTU/hr$$

or 1000×335 kJ in 24 hr

$$= \frac{1000 \times 335}{24 \times 60} = 232\ kJ/min$$

Taken as 210 kJ/min or 3.5 kJ/s.

2000 lbs = 909.1 kg
L H f ice = 335 kJ/kg
Heat removed to for 1 British Ton of ice from 0°C water to 0°C ice

$$\frac{909.1 \times 335}{24 \times 3600} = 3.52\ kJ/sec = 3.52\ W$$

3) Refrigeration by expansion of air:-

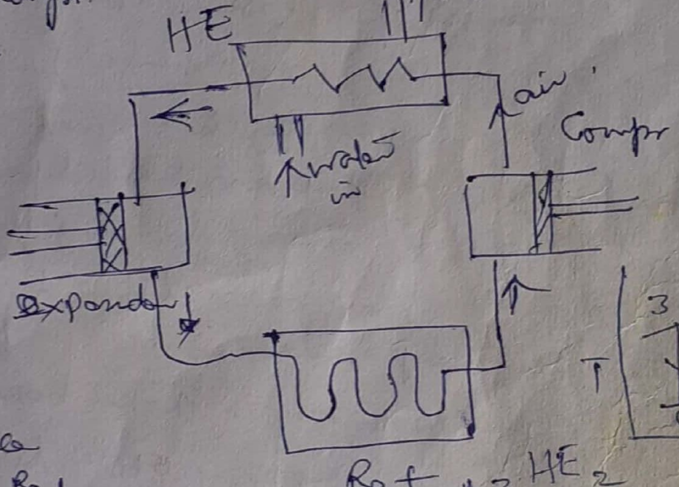
Bell-coleman air-refrgn system.

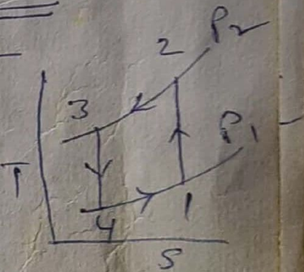
i) air is compressed in Compr.

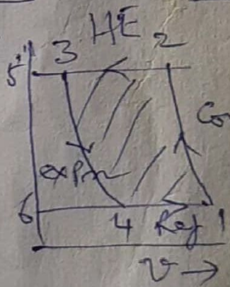
ii) High pr, High temp air is cooled in HE by water

iii) expanded isentropically in expander till it reaches atmospheric pr. Cooling takes place

iv) Cooled goes to Ref. gains heat and process repeats.







4) Ref by throttling of gas.

$$\mu = \left(\frac{\partial T}{\partial p}\right)_h$$ at Const enthalpy process

μ = Joule thomson co-efficient.

$\mu = 0$ at inversion point.

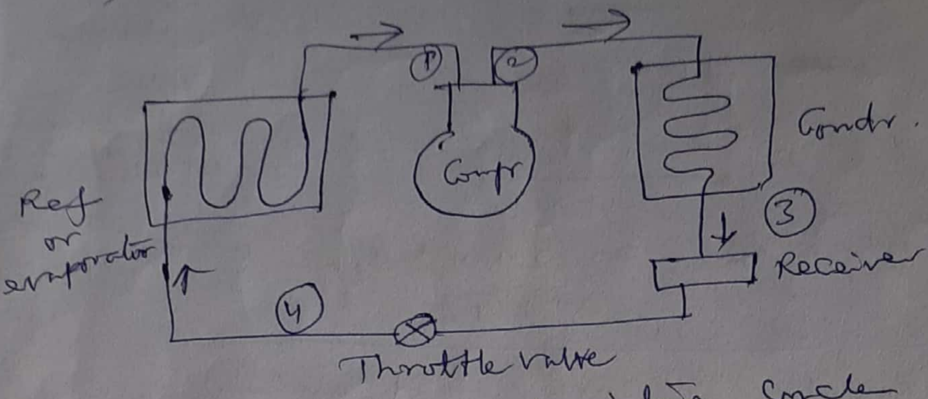
To reduce the temp after throttling μ must be +ve.

~~[illegible]~~

~~[illegible]~~

5) Vapour Refrigeration System

5) a) Vapour Compression Refgn System.



Refrigerants are used in the cycle

Ammonia, Freons etc.

Change of phase takes place in this cycle

In Air refgn no change of phase takes place

Vapour Compr cycle is shown

(1) Refgnt is compressed in Compr.

2) Cooled in Condsr (3) fills up in Receiver

4) expanded by throttling device (valve or capillary tube)

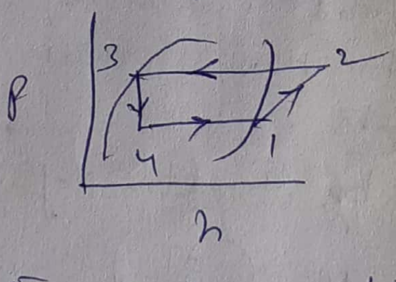
Pr, Temp reduces.

(1) goes to evap. Takes heat from products

Becomes a vapour, goes to Compsr

Cycle repeats

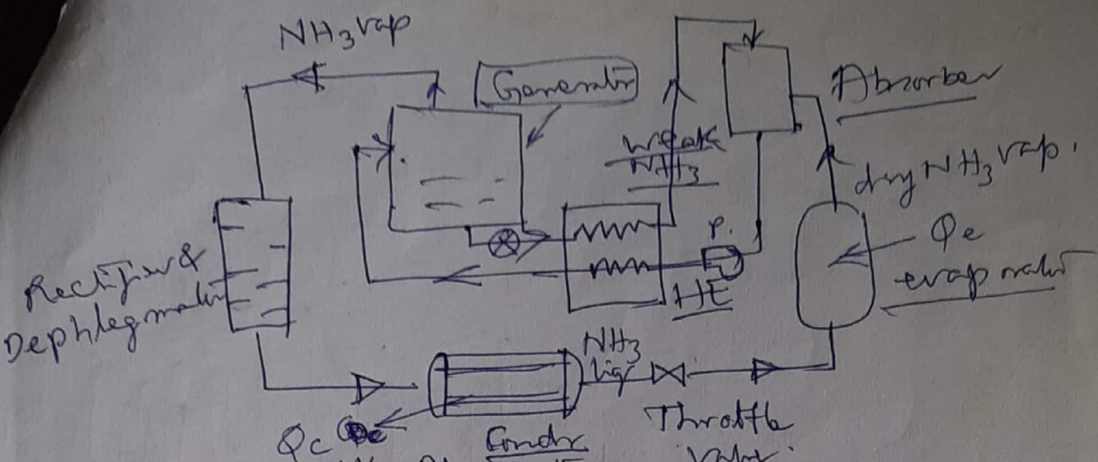
This is widely used.



5 (b) Vap Absorption System.

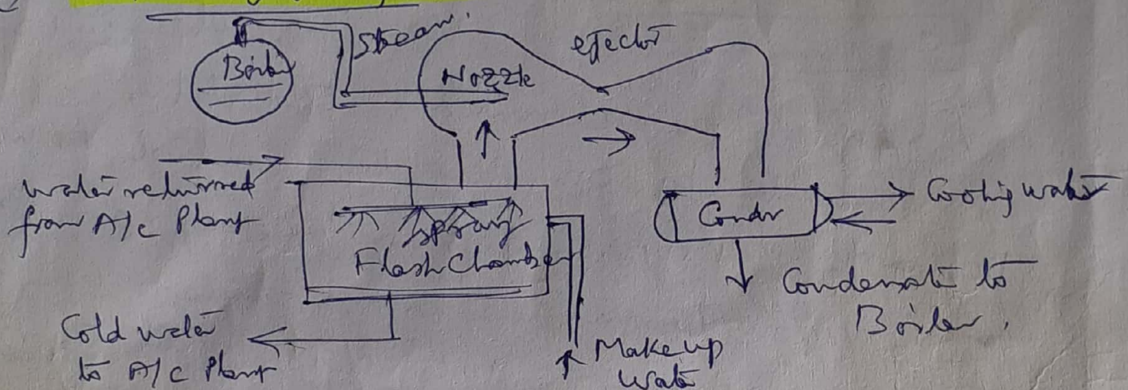
In ammonia Absorption System, water is the absorbent & NH_3 is refgnt.

From Generator NH_3 vapour goes to Condr, NH_3 liq is formed, throttled and goes to evaporator, gains heat & the dry NH_3 vap goes to Absorber, Here in absorber weak NH_3 soln mixes with NH_3 vap & becomes strong soln & goes to Generator. Cycle repeats.



NH_3 Absorption system.

(6) Steam Jet Ref.



Steam Jet Refrgn.

water boils at temps below 100°C, if the pressure on the surface of water is reduced below Atmospheric pressure. (Ex:- water boils at 6°C if the pressure on the surface is 5 cm of water).

High pressure steam is expanded in the Nozzle. water vapour from flash Chamber is entrained with the high velocity steam jet & is further Compressed in the thermocompressor. & goes to Condenser. The Condensate goes to boiler.

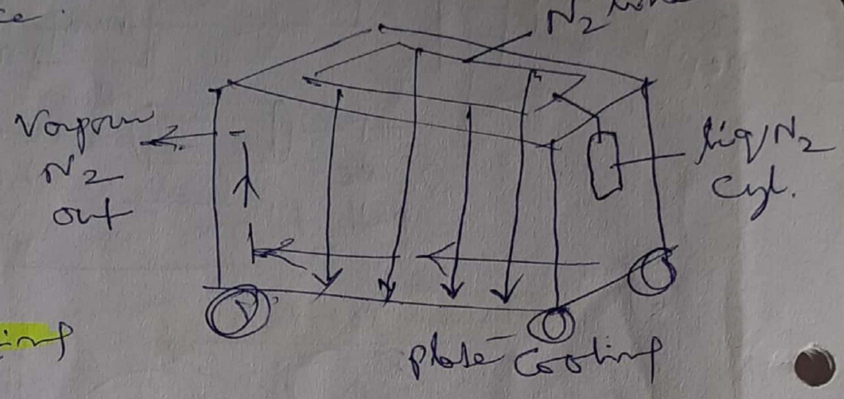
The chilled water in evaporator is pumped to A/C Plant and again returned back to the evaporator. and the cycle continues.

ex:- 100 kg water, 1 kg boiled in steam jet process.

99 kg is remaining water, $\rightarrow \frac{2394\ kJ}{4.2 \times 99} = \Delta T = 5.7°C$ fall in Temp.

7) Refrgn by using liquid gases.

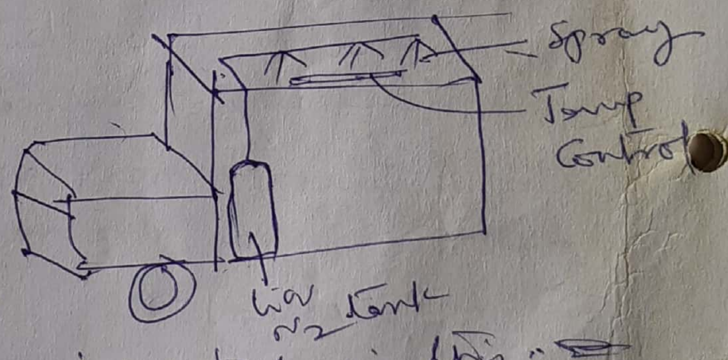
The use of liq N_2, liquid CO_2 for cooling transportation vehicles is gaining importance.



a) Cold Plate Cooling System

liq N_2 is passed into the cold plates. It is controlled by operating the control valves. liq N_2 vapourises gaining heat from products. N_2 vapour leaves the cargo space. There is no direct contact of N_2 with cargo. Temps between $-30°C$ to $20°C$ are possible to attain.

b) Spray cooling.



In this liq N_2 is directly sprayed into the refrigerated area. Safety is more important in this. (N_2 or CO_2 can be used). If liq N_2 touches the human body, the part gets frozen.

8) Dry ice Refrgn

Dry ice is Solid CO_2. Sublimation Temp is $-78°C$. It is used for frozen food. Slabs of dry ice are packed in between the food packets. This is generally used in Air craft transportation.

Necessity of Refgn.

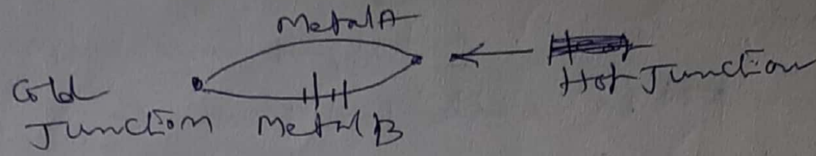
At lower temps, growth of bacteria that spoil the food, retards. Refrigeration helps in preserving the ~~food~~ Perishable food Products for longer time

Applications of Refgn:

1. Manufacturing of Ice ~~by~~
2. Preservation of food ~~to re~~ by reducing the Perishable characteristics.
3. Cold Storages - To preserve food, vegetables, fruits etc & release to market when required
4. Storing of food, making of ice cubes, keeping the drinking water cool in domestic Refrigerators.
5. Cooling of water in water coolers, ice cream in deep freezers. etc
6. Refrigeration is used in food processing industries, like ice-cream, milk, cheese etc
7. Used in chemical industries, refineries, paper, pulp industries etc
8. Refrigeration & humidity control is useful in Textile industries
9. Fruit Juices & beverages taste good when served cold. Hence Refrigeration is used
10. Refrigeration is used in Comfort Air Conditioning
11. For better quality ~~of~~ of product & comfort for workers, industrial A/c is used
12. Refrigerated trucks/vans are used to keep the food/vegetables/Fruits during transportation
13. For human comfort Refrigeration & A/c principles are used in transportation (A/c buses, A/c cars, A/c in Aeroplanes)
14. low ~~temp~~ Temp Refrgn is used to achive liquefaction of gases.

other methods of Refgn

1) Thermoelectric Refgn.



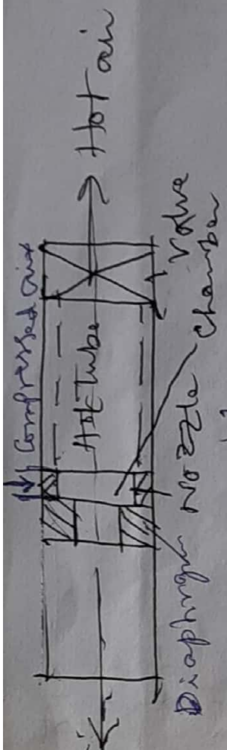
Depends on Seebeck & Pelltiere effect. when two dissimilar Materials are Connected as shown in fig and Current is passed then Cooling is observed at one Junction.

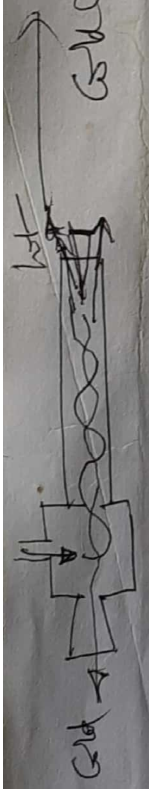
~~[illegible]~~

2) vortex tube Refrigeration :-

Here compressed air passed vortex tube consisting of Nozzle diaphragm. Rotational motion is created and hot & cold air streams are separated. Cold air is used for A/c applications & hot air is discharged outside.

(nozzle, diaphragm, valve, hot air side, Cold air side)





Properties of Air & other principles.

DBT, WBT, RH, Moisture Content.

principles of Cooling, Cooling & dehumidification, Heating & humidification.

Heat load calculations in brief.

principles of Sensible Heat, latent heat, Total heat. Sensible Heat ratio.

Comfort of human beings.

evaporation Causes Cooling.

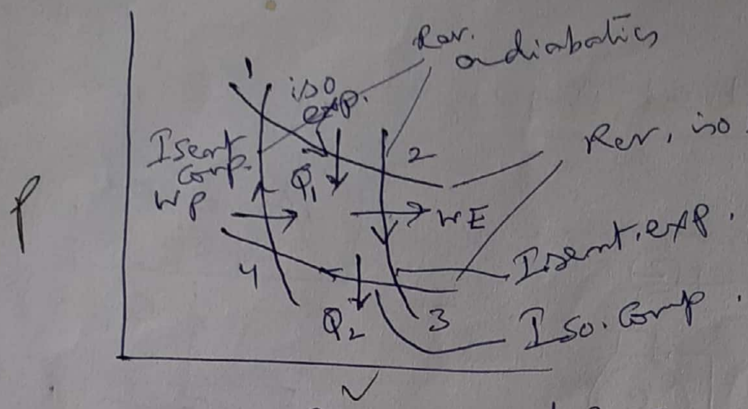
Co-efficient of performance (C.O.P).

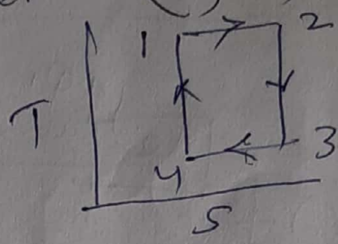
Vortex Tube :- chamber is a portion of nozzle. Chambers are gradually converted into spiral form. valve obstructs the flow of air through hot side & controls the qty of hot air through vortex Tube. A stream at core passed through diaphragm hole. Cold air Comes out from Cold side.

Engine, Refrigerator & Heat pump.

Carnot cycle

$\eta = 1 - \frac{T_3}{T_1}$





1) 1-2 → Rev. isothermal process (t_1). Heat Q_1 enters. (Reversible)

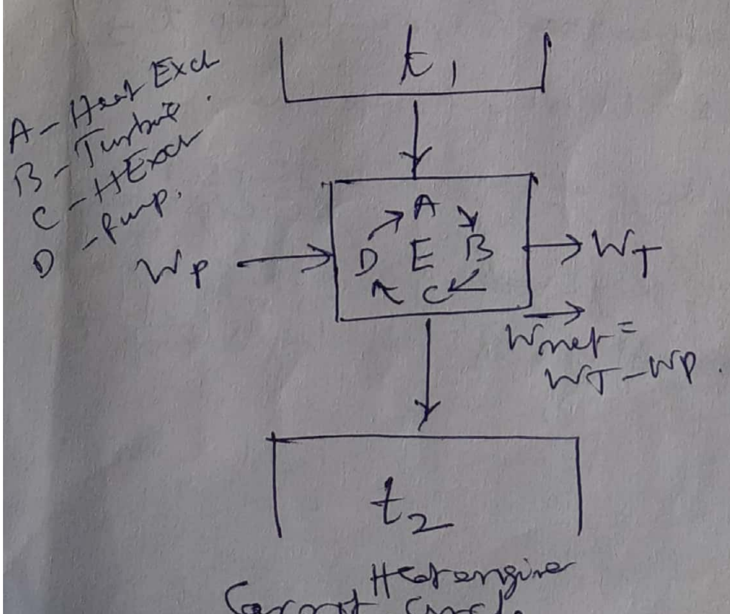
2) 2-3 → Rev. adiabatic → W_E work is done by system. Temp decreases from t_1 to t_2 (WE or W_T)

3) 3-4 → Rev. isothermal process. Heat Q_2 leaves the system at t_2

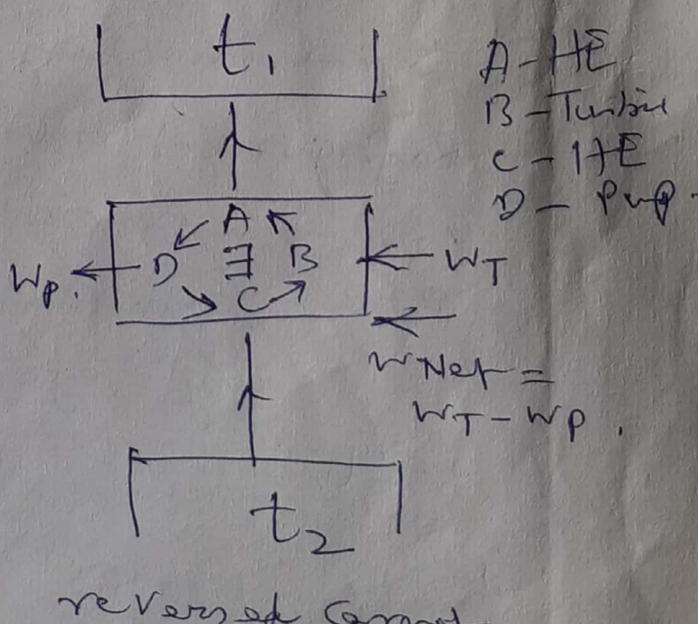
4) 4-1 → Rev. adiabatic process. W_P is done upon the system. Temp rises from t_2 to t_1.

Reversed Carnot Cycle:

Since all the processes of Carnot Cycle are reversible, it is possible to imagine the reversed processes.



Carnot Heat engine Cycle



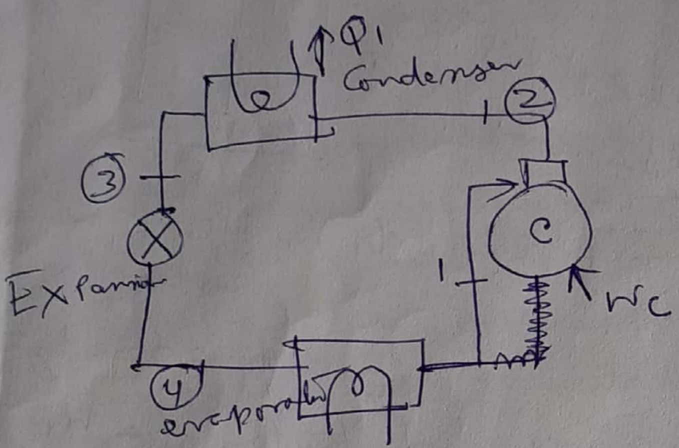
reversed Carnot Heat engine Cycle

12

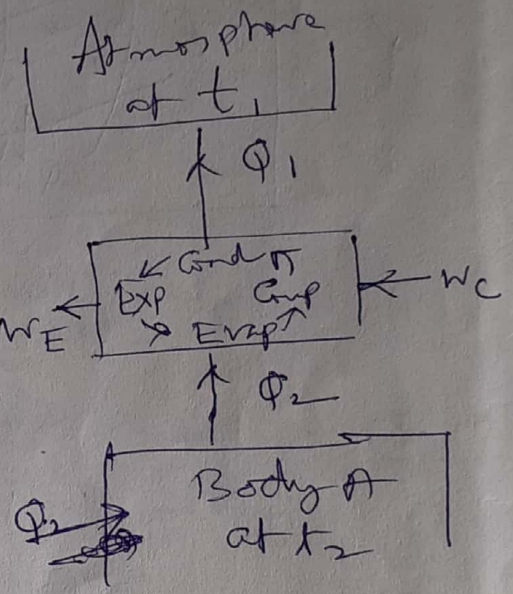
Reversed Heat engine

Here heat is taken from low temp body & discharged to high temp body, receives inward flow of work.

Refrigerator & Heat pump:-



Cyclic Refgn plant.



Refrigerator :- maintains a body at a temp lower than the temp of surroundings. let body A be maintained at t_2 which is lower than the ambient temp t_1. Even though 'A' is insulated, heat leakage Q_2 into the body will always be there from surroundings. This Q_2 is to be removed to maintain Body 'A' at constant temp 't_2'.

Refrigerant is used as working medium.

~~1-2 — Compression of Ref vapour. Temp & pr increases (Wc)~~

~~2-3 — Condensation of Ref gas to liquid by rejection of heat at high temp t_1.~~

~~3-4 —~~

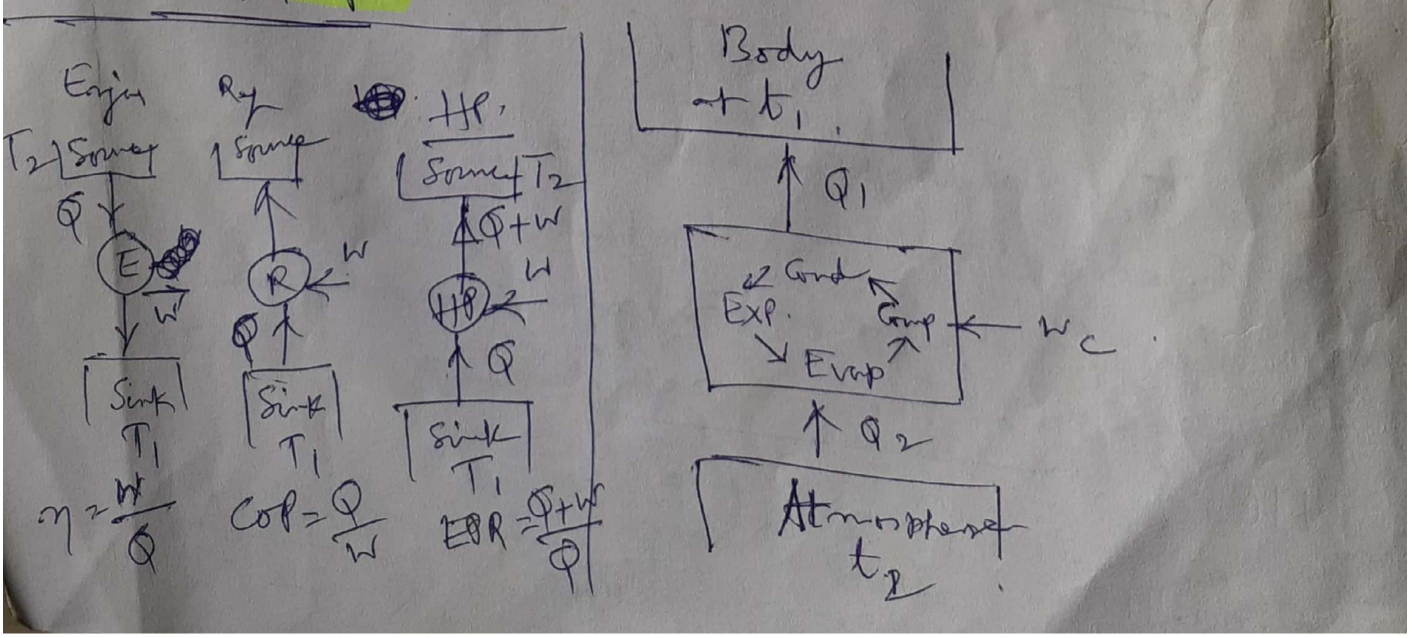
The working fluid (Refrigerant) absorbs heat Q_2 at the evaporator (refrigerant takes the heat & latent heat of vapourisation comes into picture. refrigerant becomes a vapour). (Process 4-1).
The Ref vapour is compressed by compressor (C_1) driven by motor which absorbs work (W_c) (Process 1-2)
Refrigerant becomes hot and press is raised. It is sent to condenser (Process 2-3) where heat is rejected (latent heat of condensation) in the condenser to the atmosphere or water coolant at a higher temp t_1. The refrigerant becomes a liquid but still at high temp (t_1). This condensate expands adiabatically in expansion valve & temp drops to a value lower than t_2. Cycle repeats. Such a cycle is called Refrigerator.

Co-efficient of performance = C.O.P.

$$C.O.P = \frac{\text{Desired effect or Refgn Effect}}{\text{Work input or work done}}$$

$$= \frac{Q_2}{W_c} = \frac{Q_2}{Q_1 - Q_2}$$

Heat pump.



The principle is useful in winter conditions where Atmospheric temp is low. & we want maintain comfortable hot temps in the room. Always heat transfer takes place from room to outside and in order to maintain the room temp ~~Heat~~ Heat pump principle is used. It is a simple case of Refrigerator, but evaporator ~~because the~~ & condenser are used differently.

Heat is extracted from low Temp reservoir (Atmosphere) & discharged to high temp body B with expenditure of work (work of compression). The working is similar to Refrigerator. But attention is focussed on high Temp body B.

$$(C.O.P.)_{HP} = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

Take

$$1 + \frac{Q_2}{Q_1 - Q_2} = \frac{Q_1 - Q_2 + Q_2}{Q_1 - Q_2} = \frac{Q_1}{Q_1 - Q_2}$$

ie) $1 + (COP)_{Ref} = (C.O.P)_{HP}$.

$(C.O.P)_{HP} > (C.O.P)_{Ref}$.

$\frac{Q_1}{W} = (C.O.P)_{HP}$, $Q_1 = (COP)_{HP} \times (W)$

$Q_1 = [(COP)_{Ref} + 1] \times (W)$

Q_1 is always greater than W.

For Electrical resistance heater, $Q = W$.

But for Heat pump has got thermodynamic advantage over direct heating.

HE

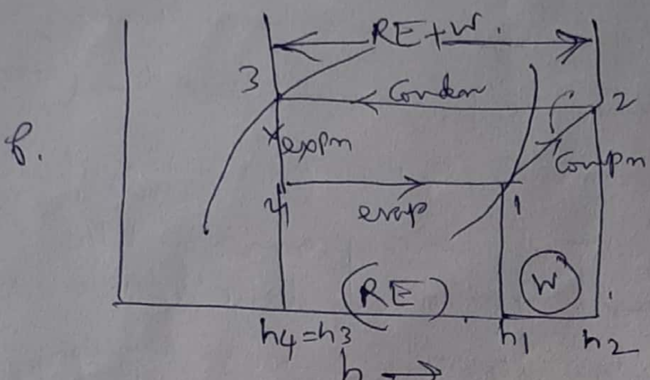
$$\eta_{Carnot\ HE} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H}.$$

$$COP_{Carnot\ HP} = \frac{T_H}{T_H - T_C}, \quad COP_{Carnot\ R} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C}$$

Relative C.O.P $= \dfrac{\text{Actual C.O.P.}}{\text{Theoritical C.O.P.}}$

Performance of heat pump is called Energy Performance ratio (E.P.R)

$E.P.R = (C.O.P)_{HP}$.



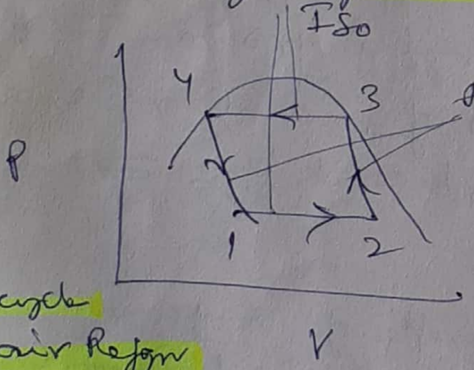
$RE = h_1 - h_4$, $W = h_2 - h_1$.

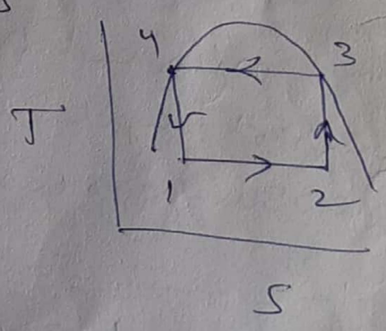
Heat rejection in condenser $= h_2 - h_3 = (h_2 - h_1) + (h_1 - h_3)$

$=$ RE + workdone. $= h_2 - h_3$.

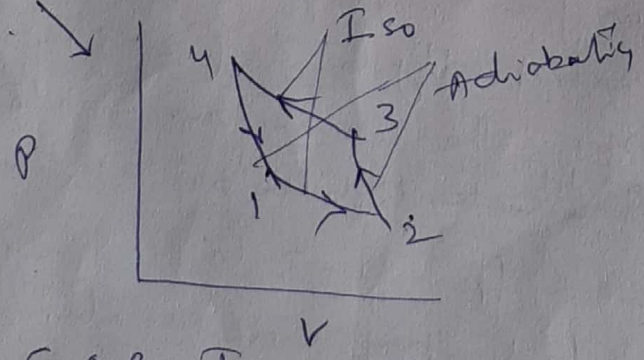
Problems 3.1, 3.2, 3.3, 3.4, 3.6,

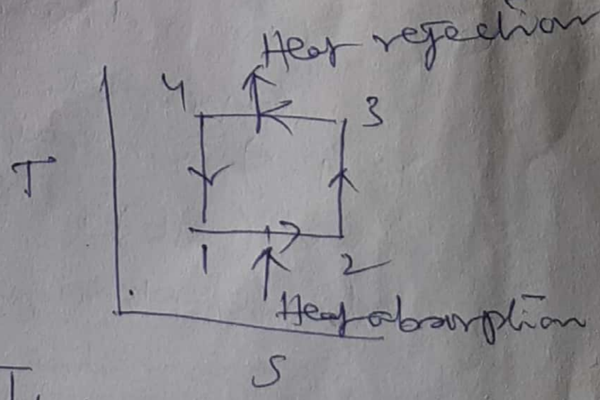
Carnot cycle for 2 phase systems (vapour Refgn)





Carnot cycle For air Refgn





$C.O.P = \dfrac{T_1}{T_2 - T_1}$ where $T_2 > T_1$.

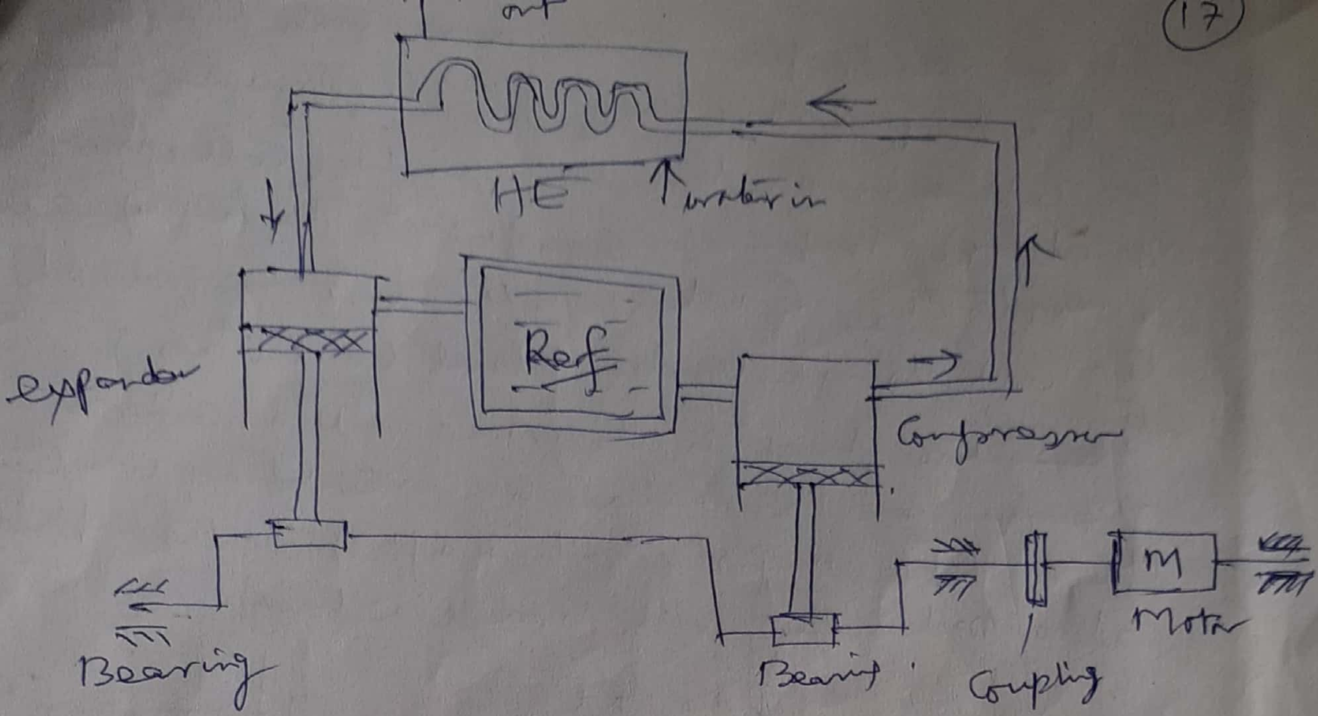
Air Refrigeration System.

The working fluid is air. Absorbing heat at low temp system & discharging the heat to high temp system is done by air., Air doesn't change the phase through out the system, unlike the vapour compression cycle where there is change of phase for the Refrigerant used (ex: Freons, NH_3). Hence the heat carrying capacity per kg of air is small compared to vapour compression M/c. The C.O.P also is less. In olden days it was used. But became obsolete for some years. Again its importance is recognised in A/c systems of aeroplane. As high pressure air is already available in aeroplane, Air refrigeration gained importance in Air craft cooling.

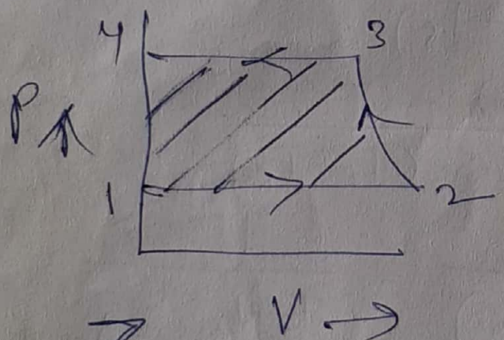
Bell – Coleman Air Refrigerator

This is one of the earliest refrigeration systems & used in ships carrying frozen meat. The isothermal processes of ideal reversed Carnot cycle are replaced by constant pressure processes.

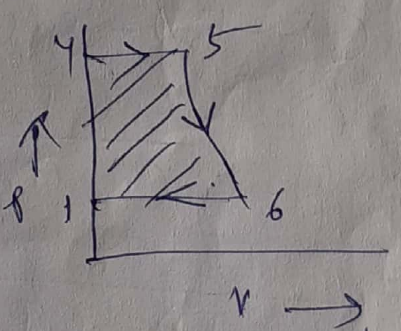
1–2 → suction stroke of compressor, (Air is drawn from refrigerator). It is compressed isentropically to 3 (2–3). Temp of air raises. The warm air goes to cooler (HE). The HE cools the air at const pr. The volume gets reduced from 4-3 to 4-5 & its temp is reduced to that of cooling water in HE. The cold air is drawn into expansion cylinder during its suction stroke (4–5) & expanded



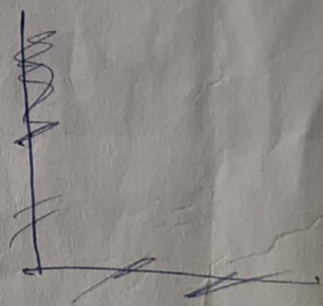
Closed cycle air Refrigerator working on Bell-Coleman cycle.

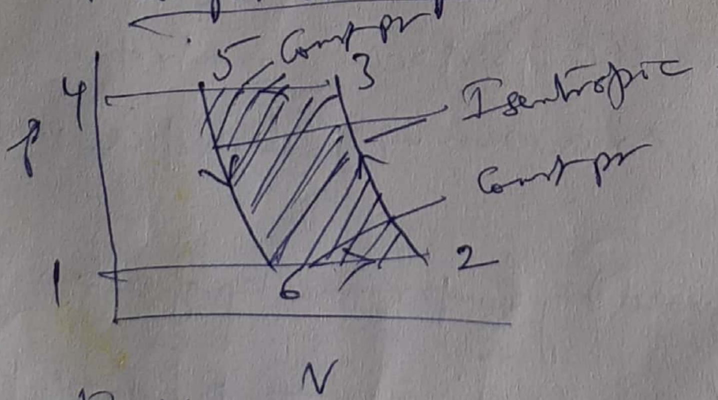


Compressor operation

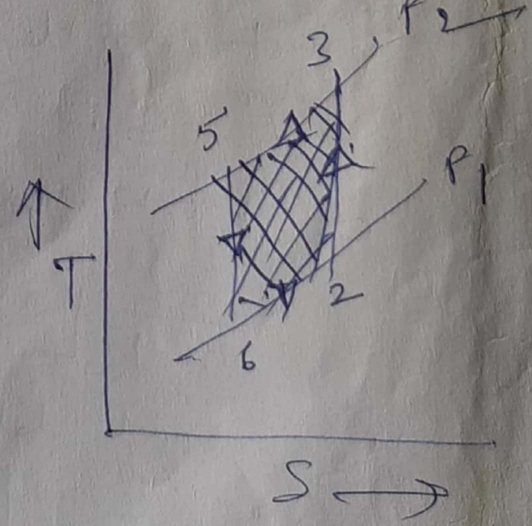


expander opn





Bell Coleman cycle

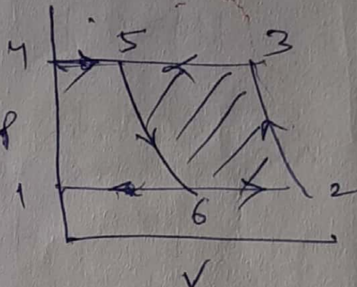


air Refrgn in T-S, diagram

The isentropic expansion cools the air to the temp below that of cold storage chamber. The cold air enters Refrigerator (cold storage) & absorbs heat at const pr. The temp of air raises to T_2 (which is the temp required in the cold storage under ideal conditions)

In this cycle the heat is absorbed in the cold storage chamber and rejected to circulating water in HE. The Refrigerating effect is the heat absorbed in the cold storage chamber.

$$C.O.P = \frac{Q}{W} = \frac{RE}{\text{workdone}}$$



W = Heat rejected − Heat absorbed

$$= C_p(T_3 - T_5) - C_p(T_2 - T_6)$$

$$C.O.P = \frac{C_p(T_2 - T_6)}{C_p(T_3 - T_5) - C_p(T_2 - T_6)}$$

$$= \frac{T_2 - T_6}{(T_3 - T_5) - (T_2 - T_6)} = \frac{1}{\frac{T_3 - T_5}{T_2 - T_6} - 1}$$

In actual practice perfect isentropic process is not possible, so assuming polytropic process $PV^n = C$.

W_c (work required by compr per kg of air)

$$= \frac{n}{n-1}\left[P_3V_3 - P_2V_2\right] = \frac{n}{n-1} \cdot R\left[T_3 - T_2\right]$$

W_e = work delivered by expander per kg of air

$$= \frac{n}{n-1} \cdot \left[P_5V_5 - P_6V_6\right] = \frac{n}{n-1} R(T_5 - T_6)$$

Work delivered by Motor in heat unit

$$= W_m = W_c - W_e.$$

$$W_n = \frac{n}{n-1} \cdot R\left[(T_3-T_2)-(T_5-T_6)\right]$$

$$C_p - C_v = R \quad , \quad \frac{C_p}{C_v} = \gamma$$

divide by C_v

$$\frac{C_p}{C_v} - 1 = \frac{R}{C_v}$$

$$\gamma - 1 = \frac{R}{C_v}$$

$$R = C_v(\gamma-1)$$

$$C_p - C_v = R$$

divide by C_p.

$$1 - \frac{1}{\gamma} = \frac{R}{C_p}.$$

$$\frac{\gamma-1}{\gamma} = \frac{R}{C_p} \quad , \quad C_p = \frac{R\cdot\gamma}{\gamma-1}.$$

$$R = C_p\left(\frac{\gamma-1}{\gamma}\right)$$

In MKS units $C_p - C_v = R/J$. , In SI units $J=1$.

$$W_n = \left(\frac{n}{n-1}\right)\frac{C_p\left(\frac{\gamma-1}{\gamma}\right)}{}\left[(T_3-T_2)-(T_5-T_6)\right]$$

$$= \left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)C_p\left[(T_3-T_2)-(T_5-T_6)\right]$$

$$C.O.P = \frac{Q}{W_n} = \frac{C_p(T_2-T_6)}{\left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)C_p\left[(T_3-T_2)-(T_5-T_6)\right]}$$

$$T_3 - T_5 - (T_2 - T_6)$$

Divide by (T_2-T_6)

$$C.O.P = \frac{1}{\left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)\left[\frac{T_3-T_5}{T_2-T_6}-1\right]}$$

As $T_5 = T_2$ for perfect inter cooling.

For isentropic, $n=\gamma$.

For ideal isentropic process

$$C.O.P = \frac{1}{\frac{T_3-T_5}{T_2-T_6}-1}$$

$$C.O.P = \frac{1}{\frac{T_3}{T_2}\left[\frac{1-\frac{T_5}{T_3}}{1-\frac{T_6}{T_2}}\right]-1}.$$

We know that by isentropic law

$$\frac{T_3}{T_2} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}.$$

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

Solve from

$P_2 V_3 = RT_3$

$P_1 V_2 = RT_2$

$P_2 V_3^{\gamma} = P_1 V_2^{\gamma}$

$\frac{P_2}{P_1} = \left(\frac{V_2}{V_3}\right)^{\gamma}$

$= \left(\frac{RT_2}{P_1} \times \frac{P_2}{RT_3}\right)^{\gamma}$

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

Hence $\frac{T_3}{T_2} = \frac{T_5}{T_6}$ or $\frac{T_6}{T_2} = \frac{T_5}{T_3}$

Substituting this

$$C.O.P.\left(\begin{array}{c}\text{isentropic}\\ \text{process}\end{array}\right) = \frac{1}{\frac{T_3}{T_2}\left[\frac{\left(1-\frac{T_6}{T_2}\right)}{\left(1-\frac{T_6}{T_2}\right)}\right]-1}$$

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

C.O.P. (Polytropic)

$$= \frac{T_2}{\left(\frac{n}{n-1}\right)\left(\frac{\gamma-1}{\gamma}\right)(T_3-T_2)}.$$

Generally if refrigerator Temp $= T_2$

$T_6 < T_2$.

For Carnot cycle. $T_6 = T_2$ (ie sink temp is Ref Temp).

In Bell Coleman cycle. $T_3 > T_5$.

If Carnot cycle is used, $T_5 = T_3$. (Source Temp).

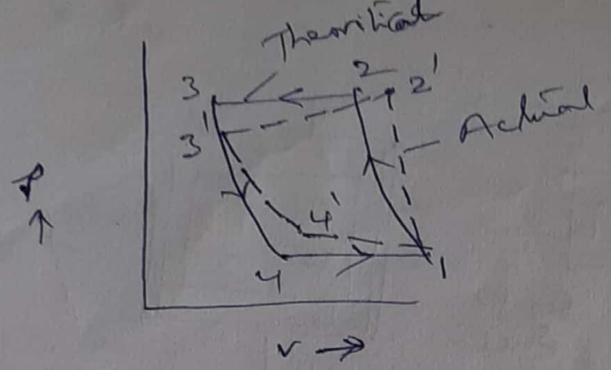
$$(C.O.P)_{Carnot} = \frac{T_2}{T_5 - T_2}$$

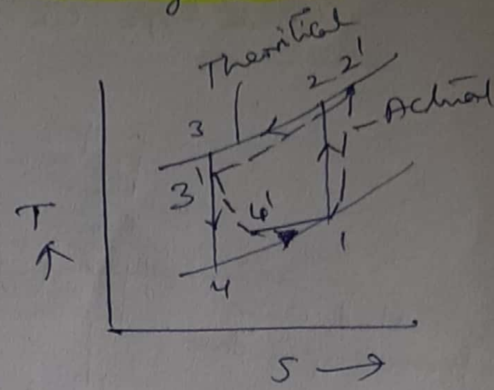
we can see that

$$\frac{T_2}{T_5 - T_2} > \frac{T_2}{T_3 - T_2}$$

$(C.O.P)_{Carnot} >$ C.O.P (Bell Coleman)

Actual analysis of Bell Coleman cycle.





Actual cycle differs in following ways

1. Compn & expn processes doesnt follow isentropic process due to friction, therefore the processes can be considered as irreversible adiabatic (increase in entropy)
2. Pressure drop takes place in Cooler (HE)
3. Pressure drop takes place in Refrigerator also. Hence pr at the outlet of expansion is greater than pr in Refrigerator. (See fig)

Advantages & disadvantages of Air Refgn System

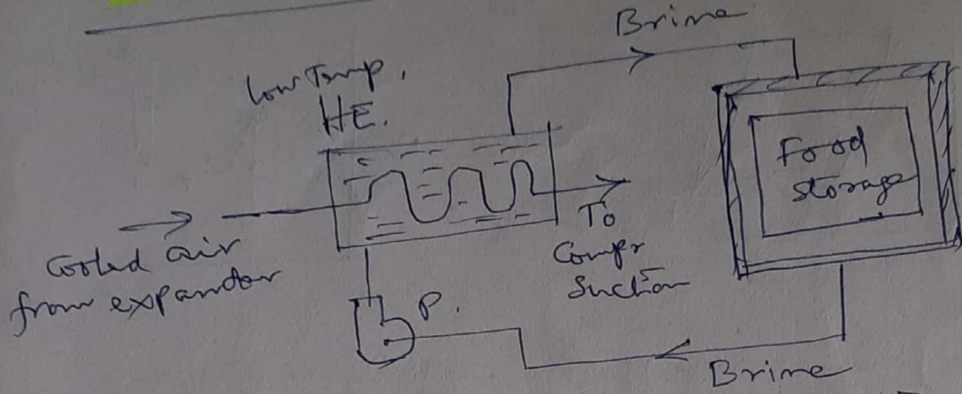
Advantages:

1. Air is easily available & cheap.
2. air is non-inflammable. So no danger of fire
3. Weight of air refgn system is lower than that of other refgn systems. Hence prefered in Air craft refrigeration.

Disadvantages

1. Heat is carried by air in the form of sensible Heat only, hence weight of air to be circulated is more than other refrigerants
2. C.O.P of system is low
3. Major disadvantage of this system is freezing of moisture in the air. formation of snow choke the valves. This is overcome in closed system.

Closed type air refgn system



Here Cold air Cools the brine & this brine is sent to refrigerated space to Cool the products. This process is known as closed system. In open system Cold air is sent directly to the refrigerated space. In closed system air doesn't Come into direct contact with Food items (Fruits, vegetables etc) Hence air can be kept nearly dry in this Case. where as in open system air cannot be kept dry. Hence frost formation will be there when low temperatures are used.

Air craft refrigeration systems

Necessity of Cooling the Aeroplane

There are many external & internal heat sources in Aeroplane. Hence A/c is required. (22°c for Comfort, -5°c for food preservation).

Major heat sources

I. External ① Heat from Sun

② Pressure of the atmosphere reduces at high altitudes. But Cabin pr should be maintained at Atmospheric pr. ~~As the~~ ~~Pressurised~~ Hence Compressed air is used for Cabin. It will be hot, ~~so refgn is~~ so A/c is ~~~~ required.

(3) Because of fast movement of plane, ~~[struck]~~ skin friction occurs all over the air craft with air, Hence heat flows into the ~~[struck]~~ cabin.
(ex An Aeroplane moving at 1000km/hr, will experience 50°C rise in temp of ~~[struck]~~ the surface.

internal Sources

(1) Human beings generate heat
(400 KJ/hr approx at rest)

(2) Electrical, electronic equipment generate heat.

(3) engine ~~[struck]~~ parts get heated up. & heat is passed to cabin.

Hence A/c is required

Factors Considered in Selecting the Refrigeration system for Aeroplane.

Air cycle refrigeration is prefered.

Advantages of Air Refgn

1) As Compressed air is available, separate Compression equipment is not required

2) weight / TR is least

3) space & volume required is less

4) Air is ~~[struck]~~ non-inflammable

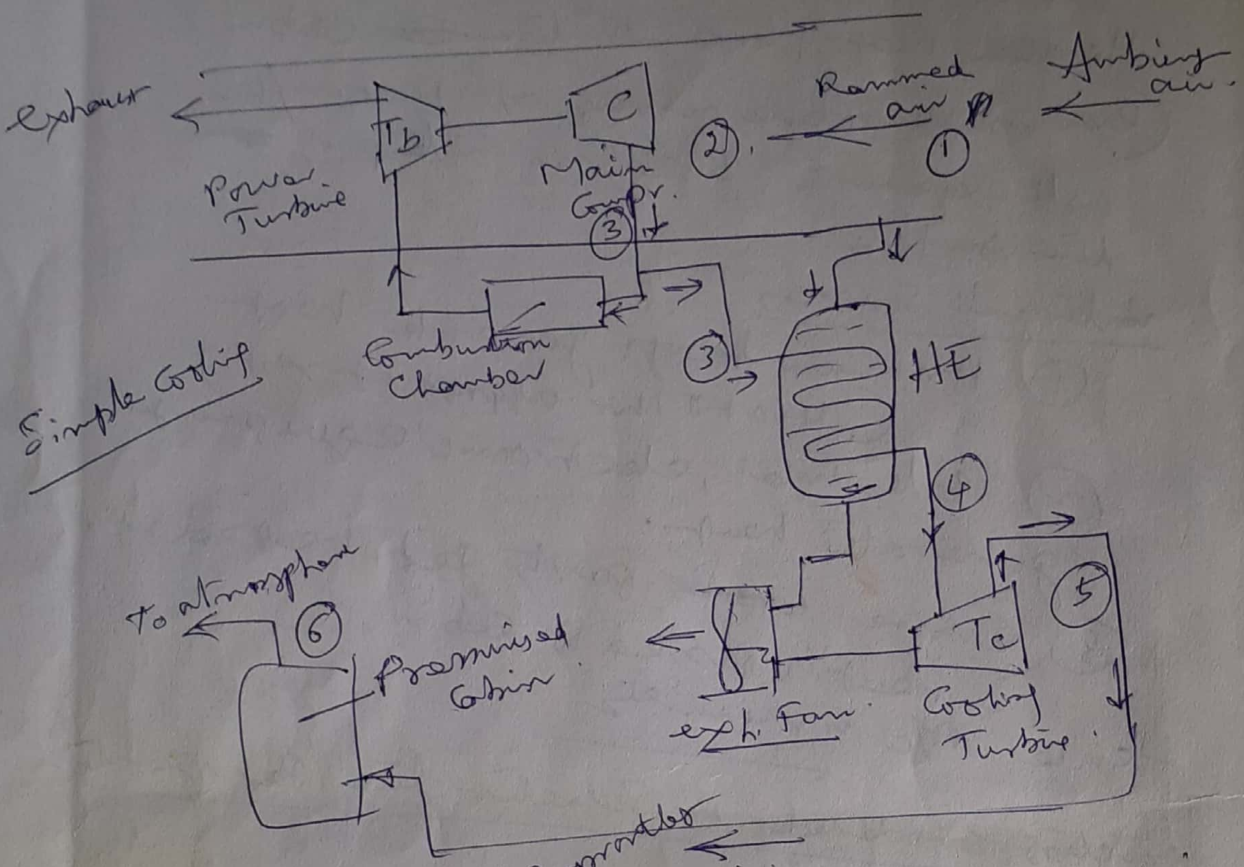
5) leakage problems with Air refgn is less

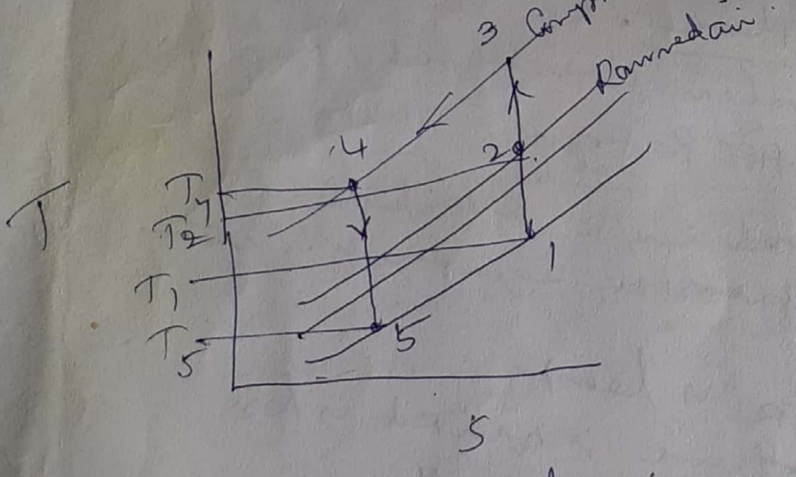
6) Maintenance ~~[struck]~~ Cost is ~~[struck]~~ low.

7) repairs are easy,

Simple Cooling with simple Evaporative Type Aeroplane Airconditioning.

Simple Cooling





1-2 ramming
2-3 Compression in Main Compr.
3-4 Cooling in HE
4-5 Expn in C.T
5-6 Heat gain

Qty of air taken for Ref purpose.

Cooling load = T Tons of Ref

$$m_a = \frac{3.5\,T}{C_p(T_6 - T_5)}$$

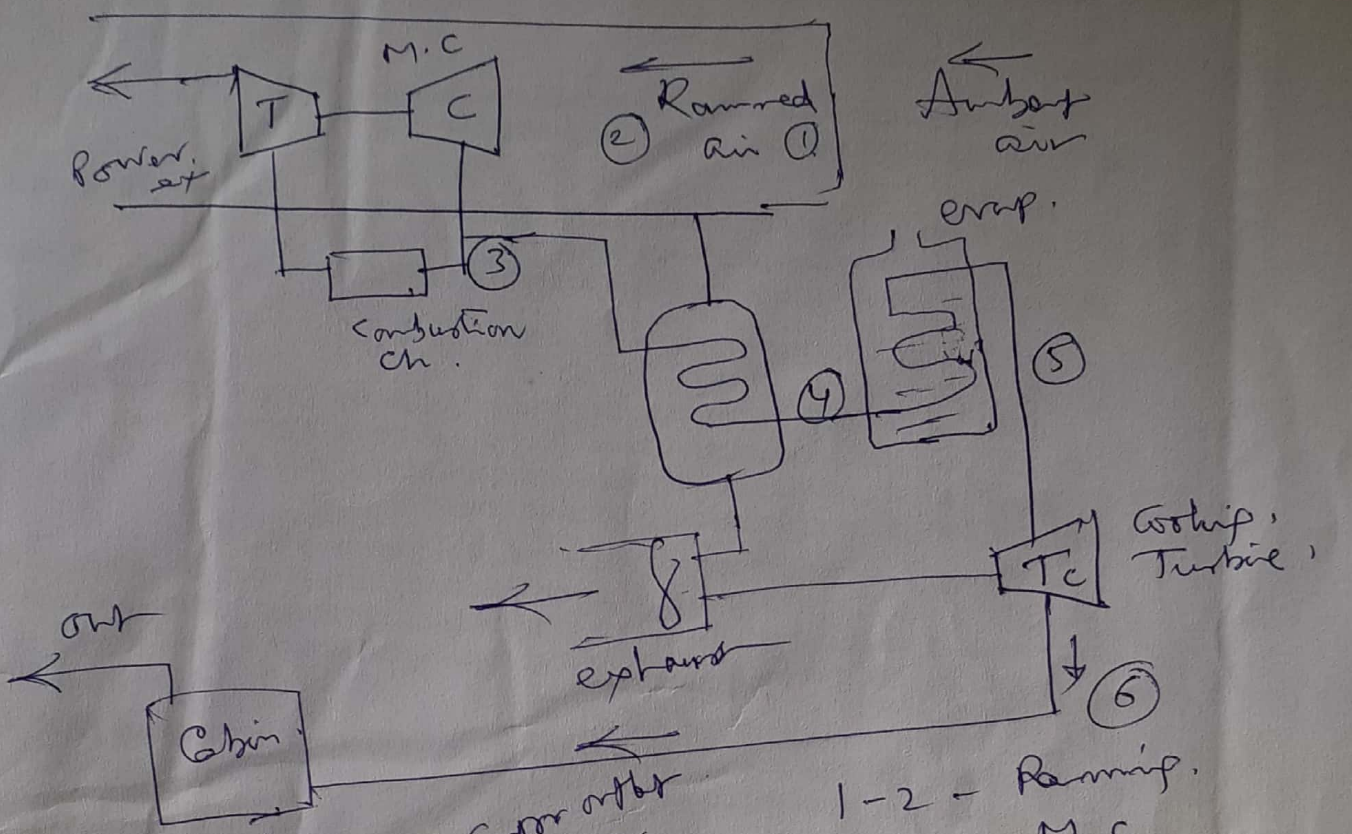
Power required kW $= m_a \cdot C_p \cdot (T_3 - T_2)$

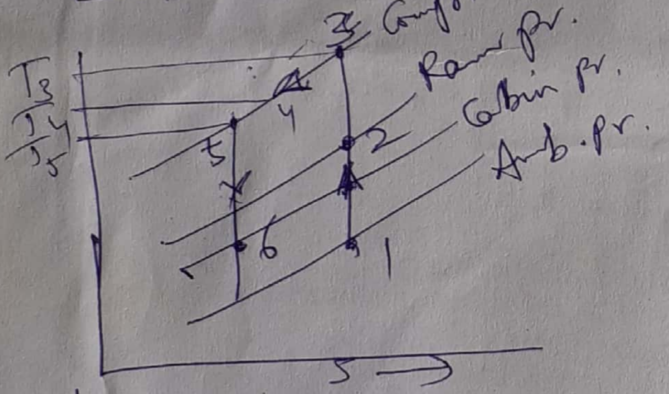
$$C.O.P = \frac{3.5\,T}{kW}$$

m_a = Mass of air per sec
C_p = Sp. ht. T = TR

Simple evaporative Type

Simple evaporative Cooling System





1-2 - Ramming.
2-3 - M.C
3-4 - Cooling in HE
4-5 - " " evap.
5-6 - Cooling Turbine.

~~water~~ water, Methyl alcohol, NH_3 all have been used in evap.

Mass of liq to be carried

m = Mass of ~~ev~~ evaporant carried

Q = Heat removed in evap.

t = ~~evap~~ Flight time in minutes

h_{fg} = L.H of ~~evp~~ evaporant in KJ/Kg

$$m = \frac{Q.t}{h_{fg}}$$

Boot strap & Boot strap evaporative Type

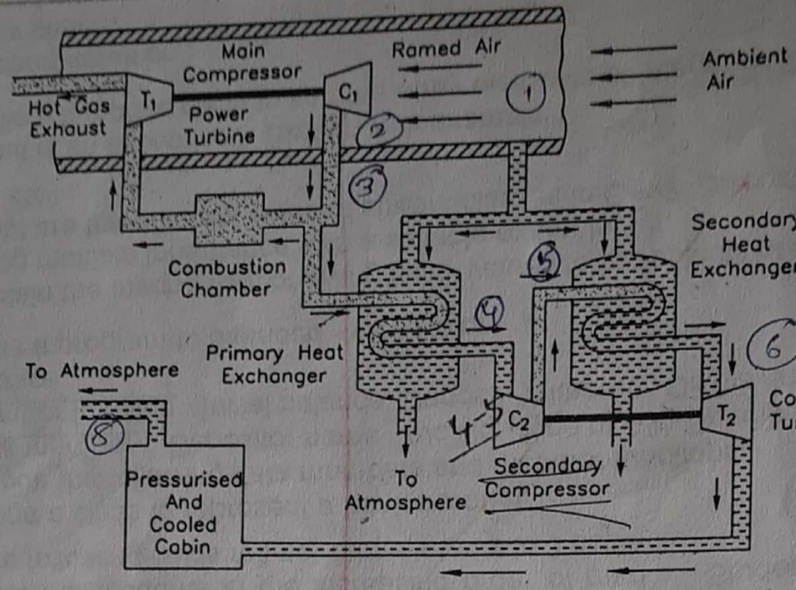


Fig. 3.13. (*a*) Boot-Strap air-cycle Refrigeration System.

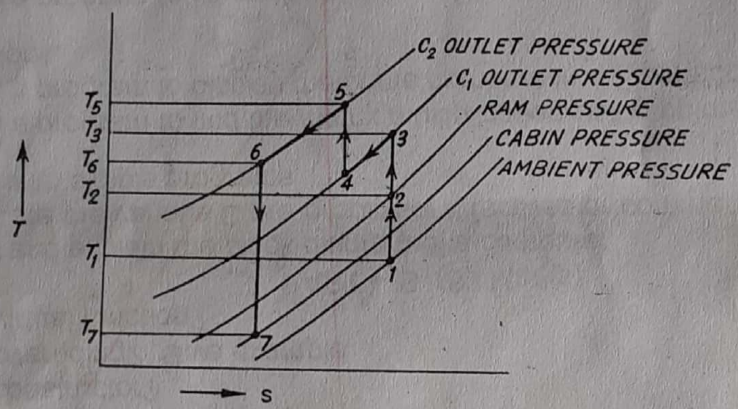


Fig. 3.13. (*b*) Representation of boot-strap cooling system on *T-s* diagram.

1 – 2 – → Ramming action.
2 – 3 – → Compression in main compressor C_1.
3 – 4 – → Cooling in the primary heat exchanger.
4 – 5 – → Compression in secondary compressor C_2.
5 – 6 – → Cooling in the secondary heat exchanger.
6 – 7 – → Expansion in the cooling turbine.

is first cooled in the primary heat exchanger. The air is then compressed to a higher pressure in the secondary compressor. It is further cooled in the secondary heat exchanger and further cooling action is completed by expanding the air through cooling turbine. Ram air is used as a heat sink in the primary and

Here the pressure of working fluid is raised to a higher level than the M.C. (Main Compressor) by a separate compr before expansion. The power required for the sec. compr is taken from the Cooling Turbine.

Boot strap air cycle refgn system is used most frequently in transport type air craft.

Cooling load is T Tons

Quantity of air circulated

$$= m_a = \frac{3.5T}{c_p (T_8 - T_7)}$$

where T_8 is the temp of air leaving the Cabin.

Power reqd = kW = $m_a \cdot c_p \cdot (T_3 - T_2)$

work reqd for sec Compr is delivered by Cooling Turbine. So no extra work is reqd.

$$C.O.P = \frac{3.5T}{m_a \cdot c_p (T_3 - T_2)}$$

Boot strap evaporative

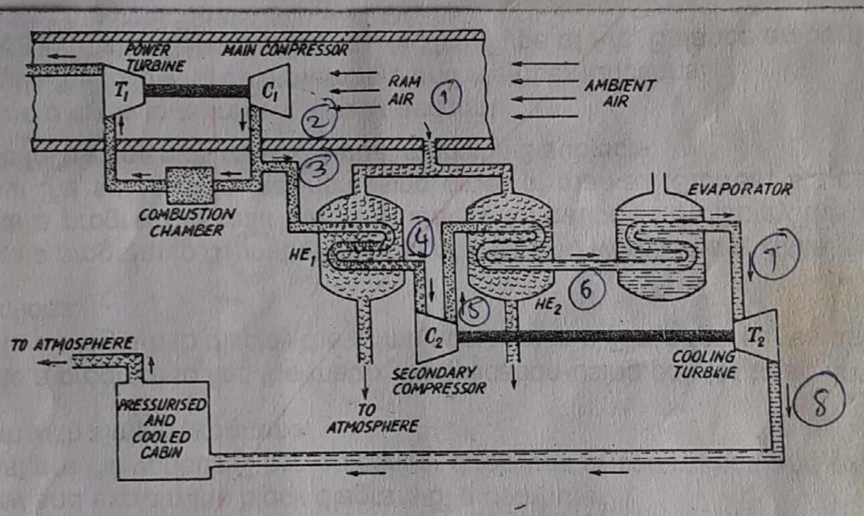


Fig. 3.14 (*a*). Boot strap evaporative cooling system.

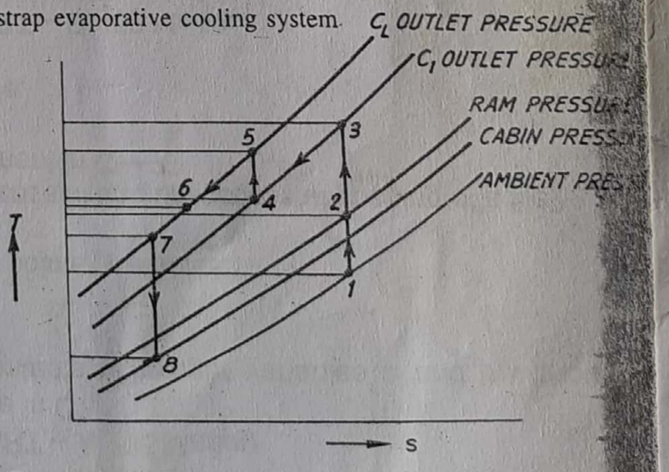


Fig. 3.14 (*b*). Representation of boot-strap eveporative system on *T-s* diagram.

cooler is located in the high pressure air duct between the secondary heat exchange and cooling turbine. Any suitable evaporant may be used as a heat sink for the evaporative cooler.

1 – 2 – → Ramming action.
2 – 3 – → Compression in main compressor.
3 – 4 – → Cooling in the primary heat exchanger.
4 – 5 – → Compression in the secondary compressor.
5 – 6 – → Cooling in the secondary heat exchanger.
6 – 7 – → Cooling in the evaporator.
7 – 8 – → Expansion in the cooling turbine.

The mass of air required in evaporative boot-strap system for taking *T* tons of load will be le the mass of air required in the boot strap system as outlet temperature of cooling turbine in evap

T_9 = outlet ~~Temp~~ Temp of Cabin Air.

The eqns are similar.

T_7 = Temp of air going out of Cabin.

$$m_1 = \frac{3.5T}{C_p(T_7 - T_6)} \text{ Kg/sec}$$

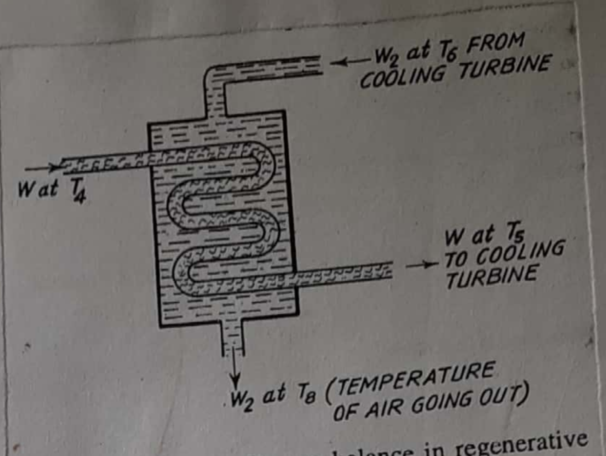


Fig. 3.15 (c). Energy-balance in regenerative heat-exchanger.

m = Total Mass from Main Compr.

m_2 = Mass used for regenerative HE.

$$m_2(T_8 - T_6) = m(T_4 - T_5)$$

$$m_2 = \frac{m(T_4 - T_5)}{(T_8 - T_6)}$$

$$KW = m \cdot C_p (T_3 - T_2)$$

$$C.O.P = \frac{3.5T}{m \cdot C_p(T_3 - T_2)}$$

Reduced Ambient Type

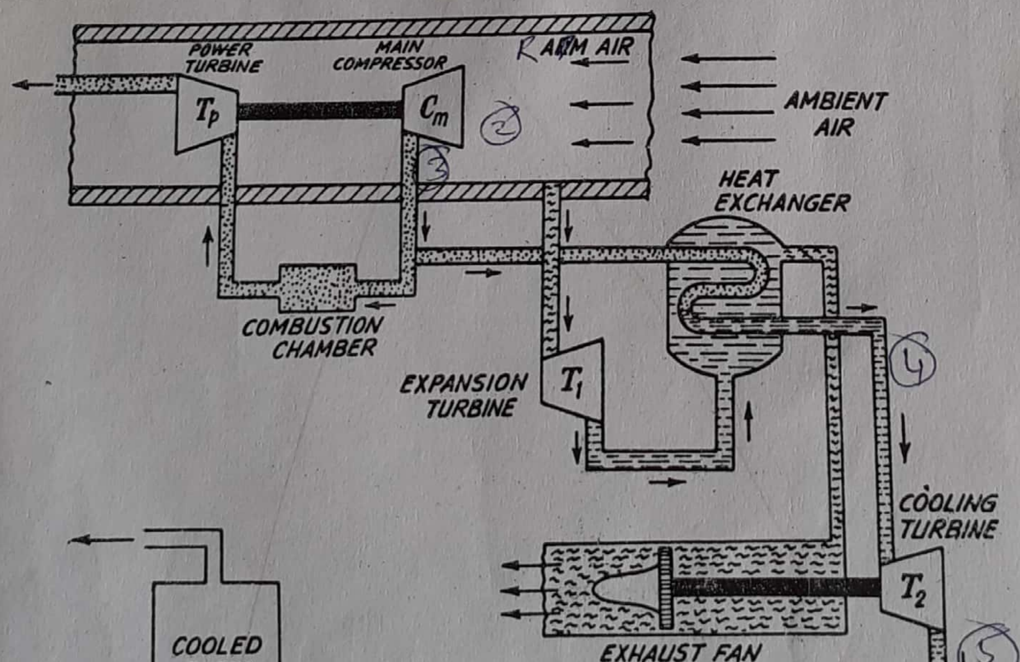
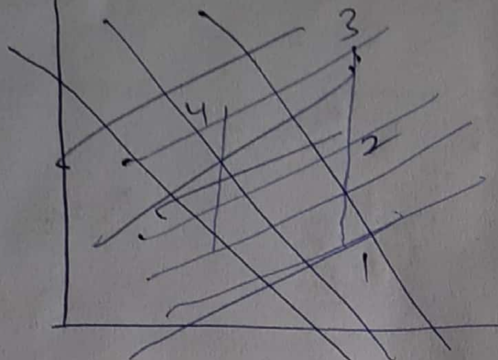
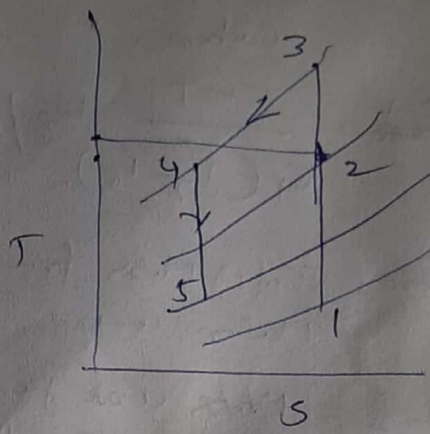


Fig. 3.16 (a) Reduced ambient type cooling system.

1 air to air HE.
2 Nos of expansion turbines.

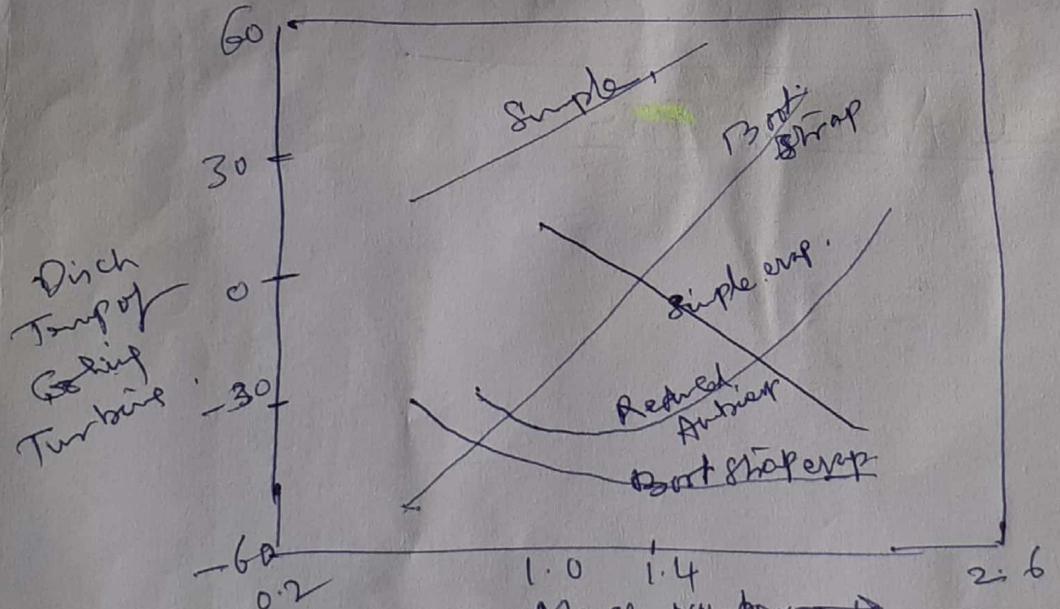




1-2 — Ramming.
2-3 — Compn in M.C.
3-4 — HE.
4-5 — Cooling turbine.

Air reqd for cooling is taken from Turbine T_1.

Comparision of diff Air cooling systems used for Air crafts.



High speed causes high disch Temp from Turbine.
Simple cooling is not effective at high speeds.
evaporative boot strap & regenerative system
give lower disch Temps. (So adopted for high speed aircrafts)

(31)

Actual ~~A/c~~ Air craft A/c with controls

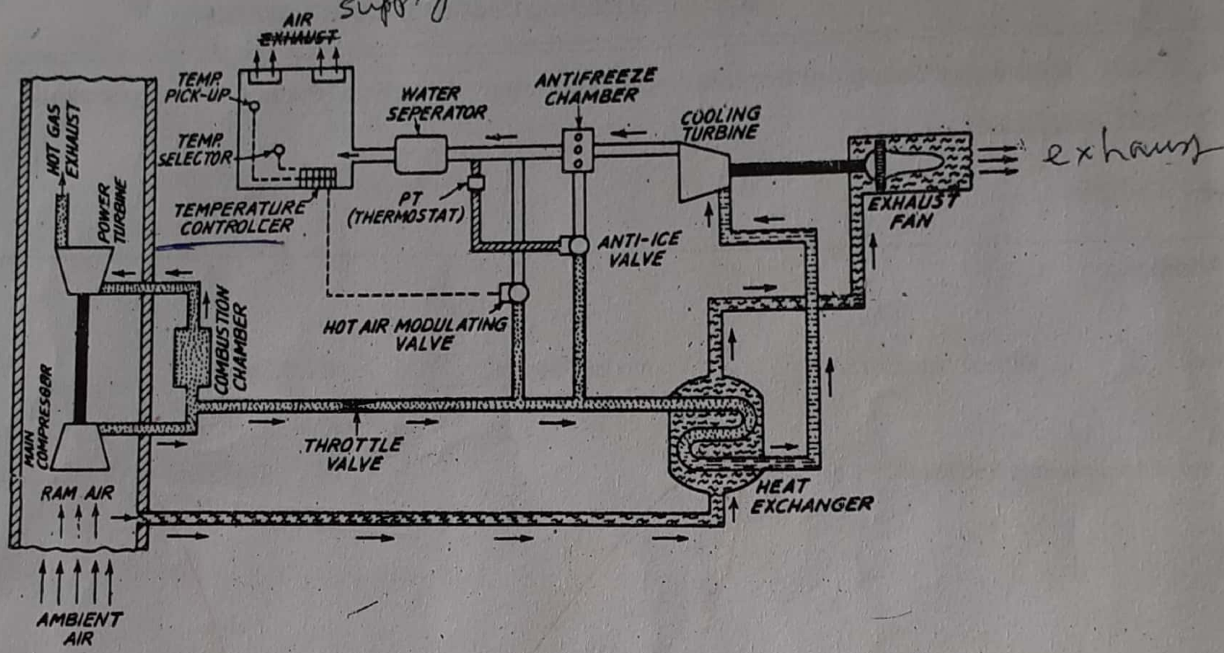


Fig. 3.22. Air conditioning system of aeroplane with controls.

Main Controls

1. Temp control in cabin.
2. Air flow (Quantity) control in cabin.
3. Water ~~~~ seperator & anti ice control.

Problems

——— x ———

3.14, 3.31, 3.29
Problems:

Refrigerants

(32)

Any substance capable of absorbing heat from another substance can be used as refrigerant.
Ex: ice, water, air, brine etc
Generally heat is extracted from lower temp body & dissipated to higher temp body either in the form Sensible Heat (as the case of air refgn) & in the form of latent heat (vapour refgn)
vapour refgn systems are more efficient.
Physical properties, pressures of refgnts must be convenient for operation of equipment.
While selecting, thermodynamic, chemical & safety characteristics of refgnts must be considered.
Air, NH_3, CO_2, SO_2, Methyl chloride were used as refrigerants, till Freons are developed.

Classification:

① Primary Refgnts
Directly take part in the Refgn System.

② Secondary Refgnts
Primary refgnt cools secondary refgnt first & then secondary refgnt cools the product.

Primary refgnts

① Halo carbon compounds.
ethane, Methane react with halogens (Cl_2, Br, F) to get compounds.

Refgnt	Chemical formula	
R-11	Trichloro mono fluoro methane	CCl_3F
R-12	Dichloro Difluoro methane	CCl_2F_2
R-22	Mono chloro Difluoro "	$CHClF_2$
R-134a	Tetrafluoro ethane	CH_2FCF_3

② Azeotropes:–
Mixture of diff refgnts which do not separate out during the process.
Ex. R-500, 73.8% F-12, 26.2% F-152

(3) Hydro Carbons:

Satisfactory thermodynamic properties but are highly flammable.

R-50 Methane CH_4, R-170 ethane C_2H_6

R-290 propane. C_3H_8.

(4) Inorganic Compounds.

R-717. – Ammonia. NH_3. — ice plants

~~R 718~~ – water (steam jet refgn)

~~R 729~~ – Air, CO_2, SO_2
Aircraft (Ships)

(5) Unsaturated ~~B~~ organic Compounds

ethylene C_2H_4

propylene C_3H_6 etc

Desirable properties of ideal Refgnt

(a) Thermodynamic properties.

1) Boiling pt :- low boiling pt is reqd.

Refgnt	B.P. at Atmospheric pr.
Ammonia.	– 33.3°C
R-12	– 29.8°C
R-22	– 41.3° C.

etc

(2) Freezing pt:, low freezing pt reqd.

Refgnt	F.P.
NH_3	–77.8°C
R-12	–157.8
R 22	–160.

(3) Evaporator & Condr pressures:

+ve pressures in evap & Condr are desirable. Too high pressures require robust designs (More Cost)

+ve pr ~~[illegible]~~ in evap is required to prevent leakage of air & Moisture

Refrg	pr in evapo -15°C	Pr in Condr at 29°C	Press ratio
NH_3.	2.34 bar	11.5 bar	4.92
F-12	1.8 bar	7.32 bar	4.07

Reciprocating compressors are used with refrgts having low specific volume.
ex NH_3, F12, F22

Centrifugal compressors are used for refrgts operating under low evap & condr pressure.

(4) Critical Temp, Critical pr:-

Critical temp of vapour is defined as a temp above which vapour cannot be condensed irrespective of any high pressure. The critical temp of the refrgt used should be higher than the condensing press for easy condensation.

Ref.	Critical Temp °C
NH_3	132.8
R-12	112.1
R-22	95.4

$CHClF_2$
m=1, n=1
p=1, q=2
m+p+q = 2(m+1)
1+1+2 = 2(1+1)
4=4

$R_{(1-1)(1+1)2} = R22$

(5) Latent Heat of Ref:- High latent heat of refrigerant at evap temp is desirable for a high refrigerating effect. If LH is high, weight of refrgt circulated is low.

Nomenclature: $C_m H_n Cl_p F_q$ methane, ethane base

P.T.O

$(n+p+q = 2m+2)$, $R_{(m-1)(n+1)q}$

$C_2Cl_2F_4$, m=2, n=0, p=2, q=4

n+p+q = 2(m+1), Designation $R_{(2-1)(0+1)4}$
6 = 6 $= R_{114}$

(B) Safe working properties :-

They include

a) Chemically inert.
b) non-flammable, non explosive, non toxic
c) Should not react with lubricating oil.
   (It should be miscible with lub oil)
d) leaked refrigerant should not have bad effect on the stored materials

1. Toxicity : Toxic nature of the refgnt will effect the humanbeings when leaked. It causes suffocation, breathing problems & death. It is a major consideration in direct expansion systems.
   * Refrigerants non toxic also become toxic when mixed with air in certain percentage.
2. Flammability : Most of the refrigerants are non flammable, so danger of explosion doesn't exist. NH_3 & CH_3Cl burn in air when present in certain concentrations. Methane, ethane, propane are highly flammable.
3. Corrosive Property :. Refgnt must be non corrosive
4. Chemically stable :- Should not decompose at normal temp encountered
5. Effect on stored product :- Should not effect quality (Colour, taste)

Ozone depletion
Global warming.
Alternate Refrigerants.

Physical properties

1) Sp. vol : low sp. vol at suction to compr is desirable
2) Sp. ht :- low sp ht of liq, high sp ht of vap "
3) Thermal Conductivity :- High conductivities "
4) Viscosity : — low viscosities are "