Refegration is the process of removing heat from a space or substance to reduce and maintain temperature lower than its surroundings.

Freonnge-1: Which is CCl_2F_2, Which was Conformed as super refegerent whic with low level of toxicity and non flamable this was the major brain in the period of refegration

principle of refegeration :-

It is defined as process of reducing and maintaing the Temperature of space or Material below the Temperature of surroundings.

In any refegerating process, the substance employed as the heat absorbers or cooling agent is called refegerent The devise producing refegeration is called Refegerator. If the devise is used for heating purpose is called heat pump

Applications of Refegeration :-

→ ~~Pressurevation~~ presevations of freshable products which are. Food stuff like fruits, vegetables, fish, meat

→ Manufactoring of ice or drynes [solid Carbon diaoxide which is the form of Co_2

→ Control of air temperature and humidity in air Conditiong system

→ preservation of medicine, blood, human tissues like eyes

→ processing of textiles and chemical products

→ Functioning of computers.

Methods of Refegeration :-

→ Natural Methods

→ Artificial (or) Mechanical methods

(a) Air Refegeration system

(b) Vapour Refegeration system.

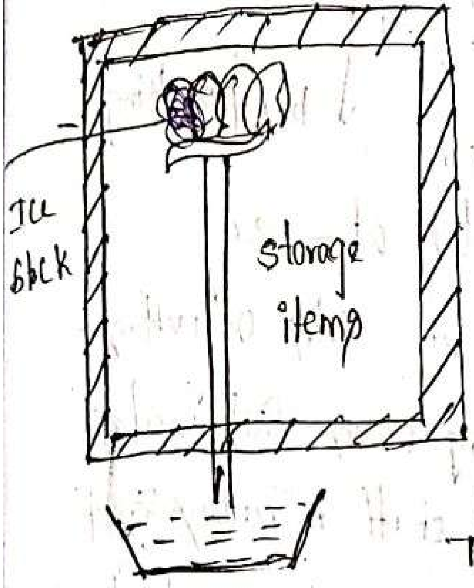
- In natural method refegeration effect is produced by bringing the substance to be cooled in direct contact with or finding Cooling medium like cold water or ~~eyes~~ ice.

- In Mechanical method refegeration ~~an~~ effect is produced by supplying the energy in the form of work or heat to operate the system. Mechanical refegeration system widely used in Industrial applications

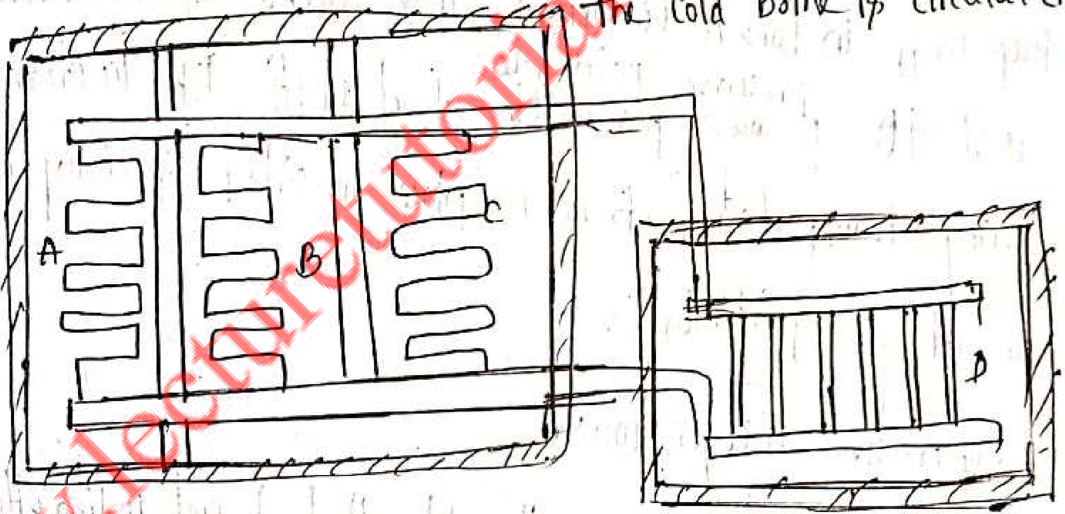
Ice Refrigeration - Most common Artificial cooling

1. Direct Method
2. Indirect method.

1. Direct Method :-



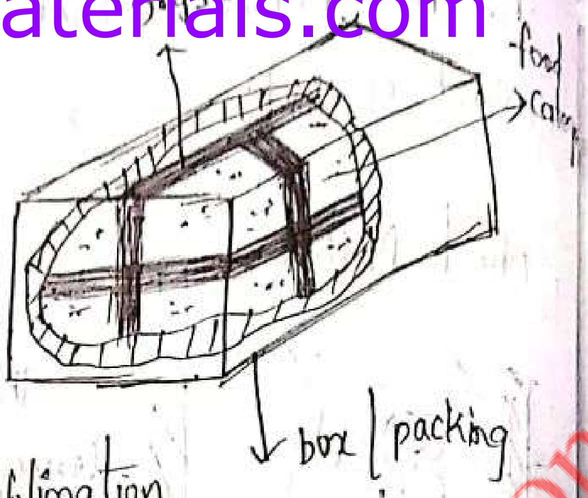
The cooling of ~~a~~ substance is carried by circulation of Brine. Brine is any liquid which is cooled by a other substance ~~Brine is~~ as the Ice is supplied to compartment D which surrounds the vertical tubes containing brine. The cold brine is circulated



To the storage spaces A, B, C to cool the articles and finally the brine returns to ice compartment D Thus cycle is repeated.

It is More suitable for large plants, no danger of ~~Cooking~~ food infection by impure ice. but intial cost is high and required large space.

Dry ice Refrigeration:-



· Dry ice is the solidified form of Co_2 it evaporates directly from solid to vapour without liquid phase

This phenomenona is called sublimation

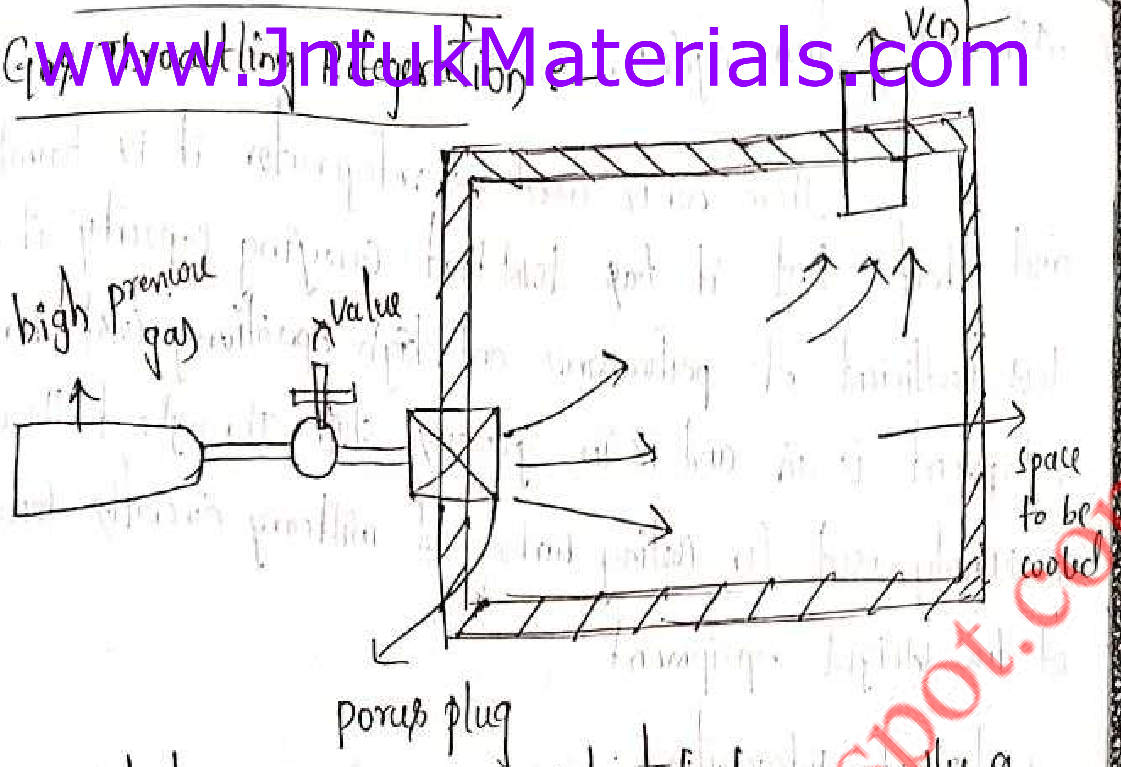
at atm pressure dry ~~ice~~ ice is sublimates at -78°c

Here Dry ice is ~~phased~~ placed on the top of sides of cuttons containing food stuff when the dry ice is sublimates at, It will absorb heat from food stuff in cuttons and keep them in forzen condition This method is extensively used to ~~preseve~~ presicrve ~~perethible~~ perichible food stuff like ice creams during transportation from one place to other specially in aircraft transportation

Evoporative refegeration:-

It is the old method to get cooling effect here water evoporates by absorbing latent heat from the surrounding air thus the air is cooled and circulated to the cold chambers

Gas Throttling Refegeration :-



For actual gasses there is a substantial change, usually a decreased Temperature. This Temp drop depends upon the pressure drop and intial state of the gas.

Here simple refegeration system working on the principle high pressure gas Throttle through porus plug in to the space to be cooled and escapes outside after absorbing heat from the space. This produceses the refegeration effect where the products kept in the space.

the Temperature drop depends Joul Thouas, the pressure drops from the intial state of the gas.

This process is called pre expansion process or throatling proces

In This process enthalaphy is to be constant those drops Constant from intial state to final state though also Temperature also drop.

Air refegeration cycle :-

Here air is used as refegerator it is harmless and cheif but it has low heat carrying capacity it has low coefficient of performance and high operationg cost here refegerent is air and is in gaseous state throughout the cycle is Mainly used for cooling carbo and milteary aircrafts because of low weight equipment.

units of refegeration :-

It is expressed in ~~ton~~ tonne of refegeration.

A tonne of refegeration is defined as the amount of refegeration effect produced by the uniform melting of one tonne of ~~kg~~ ice from and at 0°c in 24 hours latent heat of ice is 335 KJ/kg.

For 1 tonne of refegeration

$$1TR = 335 \text{ KJ in 24 hours}$$

$$= \frac{1000 \times 335}{24 \times 60} \text{ KJ/min}$$

$$= 232.6 \text{ KJ/min}$$

→ For actual practise 1 TR is to be taken 210 KJ/min (or) 3.5 KW, 3.5 KJ/sec.

C.O.P of refegerator:- Co efficient of performance:

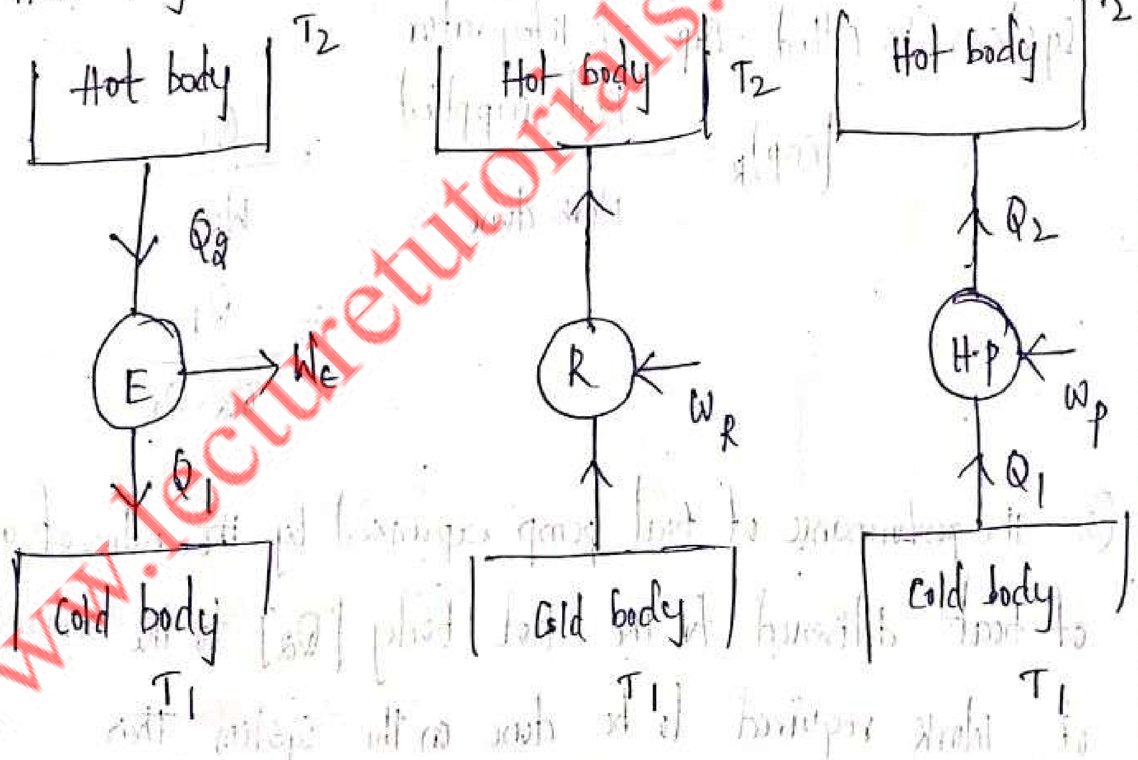
It is the ratio of heat in the refegerator to The Workdone on the refegerent. Theoritical. COP $= \frac{Q}{W}$

Then; Q = capacity of refegerator

W = Amount of Work done.

→ Relative cop $= \frac{\text{Actual c.o.p}}{\text{Theoritical c.o.p}}$

Difference b/w a ~~heat engine~~ heat engine refegerator and heat pump :-



Heat Engine.	Refegerator	heat pump
$W_E = Q_2 - Q_1$	$W_R = Q_2 - Q_1$	$W_P = Q_2 - Q_1$
$T_1 >$ atm Temp	$T_1 <$ atm Temp	$T_1 < T_2$

The performance of heat engine is expressed by efficiency (or) C.O. Then ~~efficiency~~ e

$$\eta_E \text{ (or) } (cop)_E = \frac{\text{Work done}}{\text{heat supplied.}}$$

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

② The performance of refegerator is expressed by cop, the ratio of amount of heat Taken from the cold body or $[Q_1]$ to the amount of Work required, (W_R) to be done on the systems is called cop of refegerator

$$(cop)_R = \frac{\text{heat supplied}}{\text{Work done}} = \frac{Q_1}{W_R}$$

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

③ The performance of heat pomp expressed by the ratio of amount of heat delivered to the hot body $[Q_2]$ to the amount of Work required to be done on the system Then

$$[cop]_P = \frac{\text{heat Supplied}}{\text{Work done}} = \frac{Q_2}{Q_2 - Q_1}$$

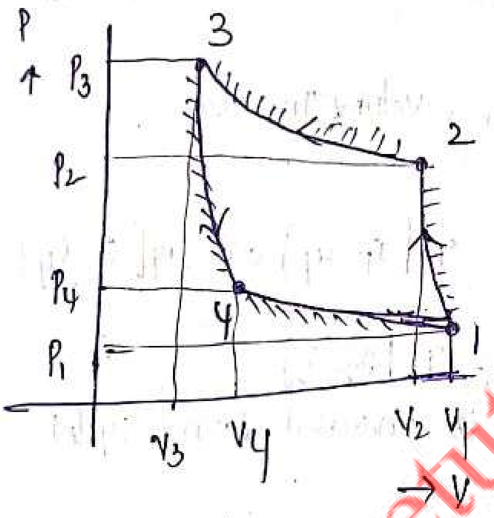
$$(cop)_P = (cop)_R + 1$$

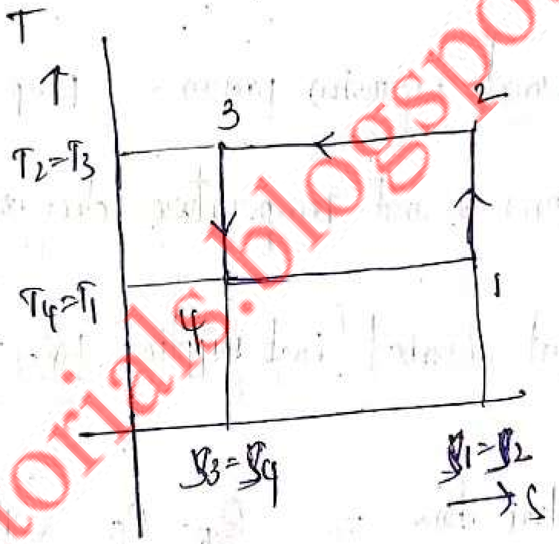
A refegerator is used for cooling in summer, & can be used as heat pump for heating in Winter.

Air refegerator working on reversed Carnot cycle:-

Here air is as working medium is shown on T.P and T-S diagram

P-V diagram





1-2 – Isentropic Compression

2-3 – Isothermal ~~Expansion~~ compression

3-4 – Isentropic expansion

4-1 – Isothermal expansion

1-2 Isentropic Compression — heat is to be maintained constant pressure is to be increased Temperature is also increases. volume decreases.

Isothermal compression – Temp is maintained to be constant pressure Increases volume decreases

heat rejected $= (Q_R) = T_2 [S_2 - S_3]$ (or) $T_3 [S_2 - S_3]$

Isentropic expansion process – Heat is maintained constant pressure and Temperature decreases, volume increases.

Isothermal expansion process – Temp is to be Maintained Constant pressure and Temperature decreases, volume Increases

Heat absorbed / heat supplied $(Q_S) = T_1 [S_1 - S_4]$ (or) $T_4 [S_1 - S_4]$

$= T_1 [S_2 - S_3]$

Work done $= Q_R - Q_S$ (It is reversed carnot cycle)

$$W.D = T_2 [S_2 - S_3] - T_1 [S_1 - S_4]$$

$$\cancel{= (T_2 - T_1) [S_2 - S_3} = (T_2 - T_1) [S_2 - S_3)$$

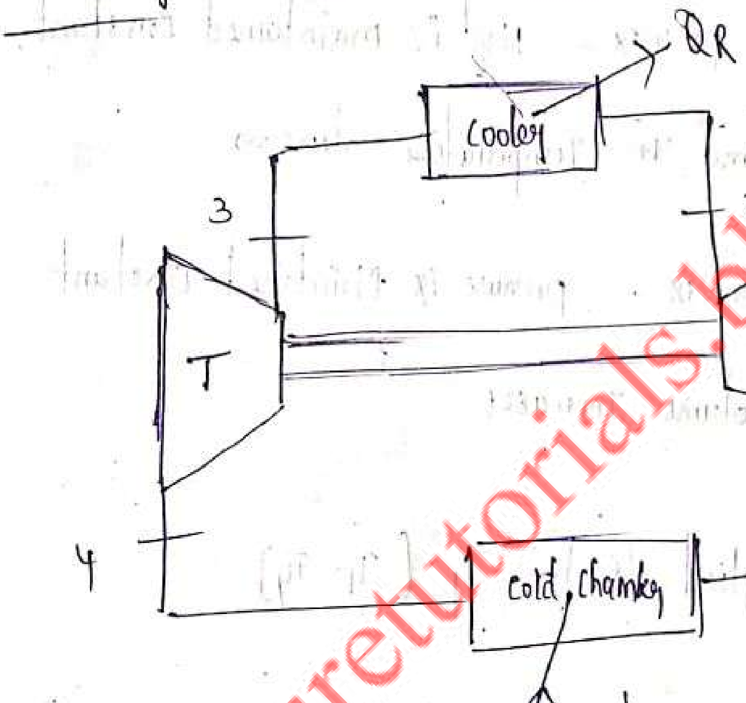
$$\cancel{(C.O.P)_R = \frac{\text{Work done}}{\text{Heat absorbed}}} = \cancel{\frac{T_2 (S_2 - S_3) - T_1 (S_1 - S_4)}{T_1 [S_1 - S_4]}}$$

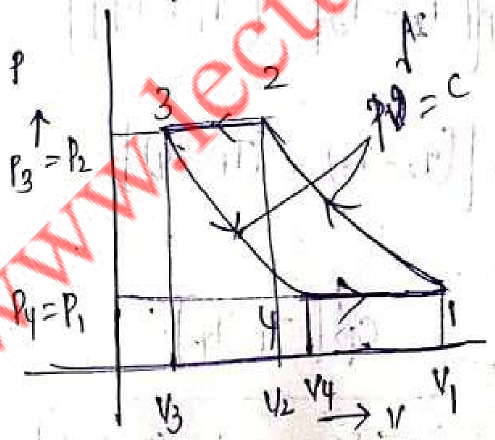
$$= \cancel{\frac{T_2 (S_2 - S_3)}{T_1 (S_1 - S_4)}} - 1$$

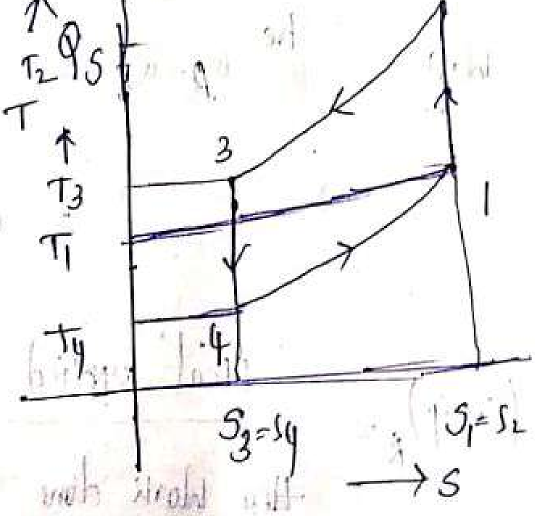
$$[C.O.P]_R = \frac{\text{heat supplied}}{\text{Work done}} = \frac{T_1[S_1-S_4]}{T_2[S_2-S_3]-T_1[S_2-S_3]}$$

$$(C.O.P)_R \Rightarrow \frac{T_1[\cancel{S_1-S_4}]}{(T_2-T_1)[\cancel{S_1-S_4}]} = \frac{T_1}{T_2-T_1}$$

Air refegeration by Belcornot cycle :-







1-2 – Isentropic compression process

2-3 – Isobaric compressing process

3-4 – Isentropic expansion process

4-1 – Isobaric expansion process

Isentropic Compression process – Heat is to be maintained const pressure and Temp increases, volum

II. Isobaric compresion process – pressure is to be maintained const ($P_2 = P_3$), Temperature decreases and volume decreases

heat rejected $(Q_R) = cp\,[T_2 - T_3]$

Isentropic expansion process – Heat is maintained constant, pressure and ~~volume~~ ~~In~~ Temperature decreases

Isobaric expansion process – pressure is maintained constant Temperature, volume Increases

heat supplied $(Q_S) = cp\,(T_1 - T_4)$

$$W.D = \cancel{Ho}\; Q_R - Q_S = cp\left[\left[T_2 - T_3\right] - \left[T_1 - T_4\right]\right]$$

$$= cp\left[(T_2 - T_3) - (T_1 - T_4)\right]$$

$$(C.O.P)_R = \frac{\text{Heat supplied}}{\cancel{Hea}\ \text{Work done}} = \frac{\cancel{cp}\,[T_1 - T_4]}{\cancel{cp}\,[(T_2 - T_3] - (T_1 - T_4)]}$$

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

①. An Air refegarator working on the principle of Bell Coleman cycle the air into the compressor is at 1 atm, at $-10°c$ it is compressed to 10 atm and cooled to $40°c$ at the same pressure It is Then expanded to 1 atm and discharged to take cooling load. the air circulation is 1 kg/sec the isentropic efficiency of the compressor Is 80%, Isentropic efficiency of the turbine is 90%. find out.

i) refegeration capacity of the system

ii) c.o.p of the system. $\gamma = 1.4$, $c_p = 1.0$ kJ/kgK

Sol Given

In polytropic compression process and expansion process

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}, \quad \left(\frac{T_3}{T_4}\right) = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

Where $P_3 = P_2$ & $P_1 = P_4$ then $\frac{T_2}{T_1} = \frac{T_3}{T_4}$

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

Sub 'T_2' in above eqn of c.o.p

$$(c.o.p)_R = \frac{[T_1 - T_4]}{\left[T_1 \cdot \frac{T_3}{T_4} - T_3\right] - [T_1 - T_4]}$$

$$= \frac{[T_1 - T_4] \times T_4}{(T_1 - \text{[illegible]})\ T_3} \Rightarrow \frac{T_4 - T_3}{T_1}$$

C.O.P $\Rightarrow \frac{T_1}{T_2 - T_1}$

$$= \frac{1}{\frac{T_3}{T_4} - 1} = \frac{1}{\frac{T_2}{T_1} - 1} = \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$C.O.P = \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

Where the pressure ratio compression and expansion ratio is denoted by (r_p) ∴

$$\boxed{(C.O.P)_R = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}}$$

Isentropic compression process are expansion process Transverse into adiabatic index of to isentropic index. $[\gamma = n]$

Work done for compression process 1-2; $W_c = \frac{n}{n-1}[P_2V_2 - P_1V_1]$

Work done in expansion process: $W_E = \frac{n}{n-1}[P_3V_3 - P_4V_4]$

$$= \frac{n}{n-1} R[T_3 - T_4]$$

$$W_{net} = W_C - W_E$$

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

Heat supplied Q_s = Refrigeration effect $Q_s = C_p (T_1 - T_4)$

heat supplied in the refegeration effect, it is denoted by N.

$$(T.O.P)_R = \frac{Q_s}{W_{net}} \text{ (or) } \frac{N}{W_{net}}$$

$$(c.o.p)_R = \frac{C_p (T_1 - T_4)}{\frac{n}{n-1} R [(T_2 - T_1) - (T_3 - T_4)]}$$

Where $C_p - C_v = R$

$$\frac{C_p}{C_v} = \gamma$$

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

Sub this value in above eqn

$$(c.o.p)_R = \frac{C_p [T_1 - T_4]}{\frac{n}{n-1} C_v [\gamma - 1] [(T_2 - T_1) - (T_3 - T_4)]}$$

$$= \frac{n}{n-1} R [T_2 - T_1]$$

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

In polytropic process When $n = \gamma$ then

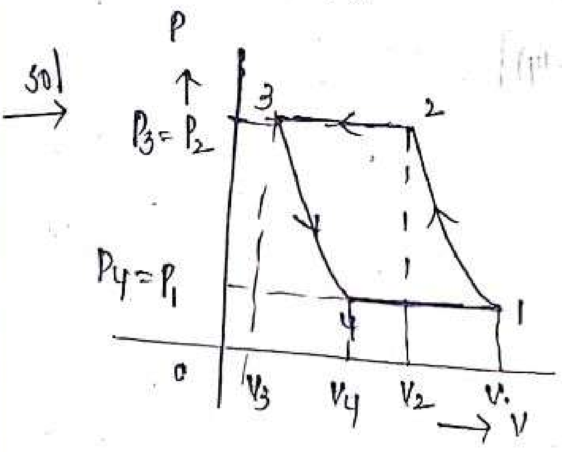
$$\boxed{(c.o.p)_B = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)}}$$

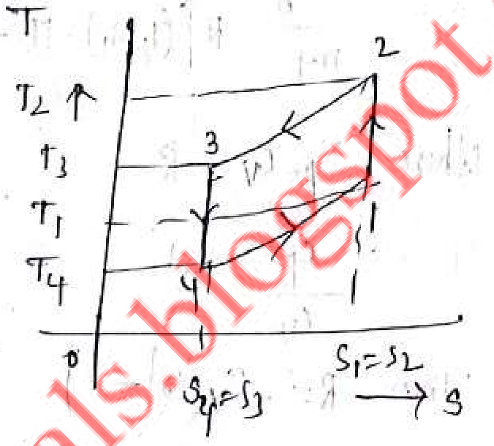
$$(c.o.p) = \frac{T_1 - T_4}{(T_2 - T_3) - [T_1 - T_4]}$$

① . In a refrigeration 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 upto 20°c in a cooler before expanding back to a pressure of 1 bar determine the Theoritical c.o.p of plant and net refegeration effect cp as 1.005 kJ/kg k

$C_V = 0.718$ kJ/kg k.

sol →





Given

$P_1 = 1$ bar $= P_4$

$P_2 = 5$ bar $= P_3$

$T_1 = 10+273 = 283$ K.

$T_3 = 20+273 = 293$ K $\quad \gamma = 1.4$

For Isentropic comp. process 1-2 $\quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$$T_2 = 283\left[\frac{5}{1}\right]^{\frac{1.4-1}{1.4}}$$

$$\underline{\overline{T_2 = 448.22 \text{ K.}}}$$

Isentropic expa- process 3-4, $\quad \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

$$\boxed{T_4 = 184.99} \text{ K}$$

$$\rightarrow \text{Theoritical } (C.O.P) = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)} = \frac{283 - 184.99}{(448.22 - 283) - (293 - 184.9)}$$

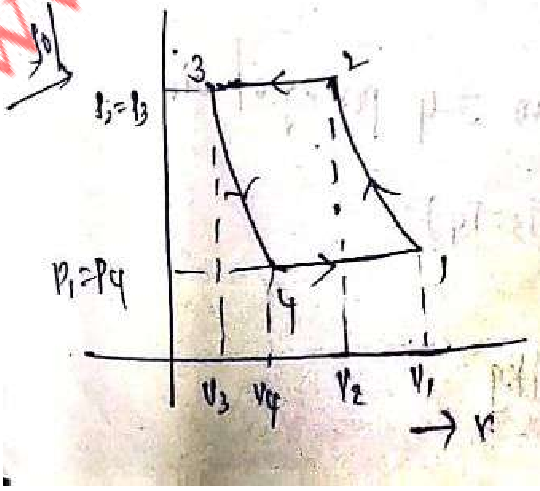
$$(C.O.P) = 1.713$$

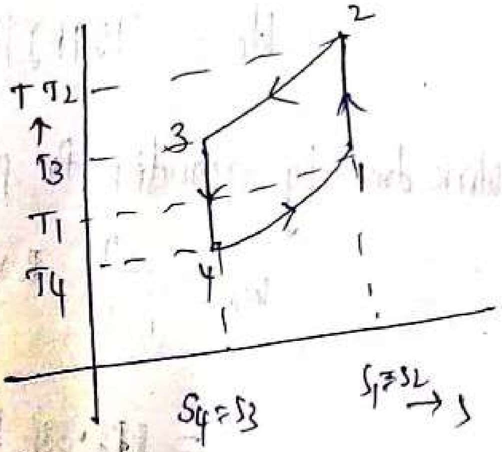
$$\rightarrow \text{net refegerating effect } Q_s / r_n = c_p (T_1 - T_4)$$

$$= 1.005 [283 - 184.99]$$

$$= \underline{\underline{98.50}}$$

② The atm air of pressure 1 bar and Temperature −5°c is drawn in the cylinder of the compressor of a bell carnot refegerating machine it is compressed issentropically to a pressure of 5 bar In the cooler the compressed air is cooled to 15°C, pressure remain same. it is then expanded to a pressure of 1 bar in an expander, from where it is passed to the cold chamber find work done per kg of air, c.o.p of the plant for air law for expansion $Pv^{1.2}$ is constant law for compression, $Pv^{1.4} = C$, Specific heat of air at constant pressure $C_p = 1$ kgJ/kg K





$P_1 = P_4 = 1$ bar

$P_2 = P_3 = 5$ bar

$T_1 = -5°C + 273 = 268$ K

$T_3 = 15 + 273 = 287$ K.

For compression process 1-2 $pv^{1.4} = C$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad \gamma = 1.4$$

$$T_2 = 268 \times \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}} = 424.8 \text{ K}$$

for expansion process 3-4 $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}}$ $n = 1.2$

$$\boxed{T_4 = 219.45 \text{ K}}$$

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

$$W_c = \frac{\gamma}{\gamma-1} \times R \times (T_2 - T_1)$$

$R = 0.287$

$W_c = 159$ kJ/kg.

Work done by expander for process 3-4 per kg of air

$$W_e = \frac{n}{n-1} R \times (T_3 - T_4)$$

$= 118.34$ kJ/kg

$$W_{net} = W_c - W_e$$

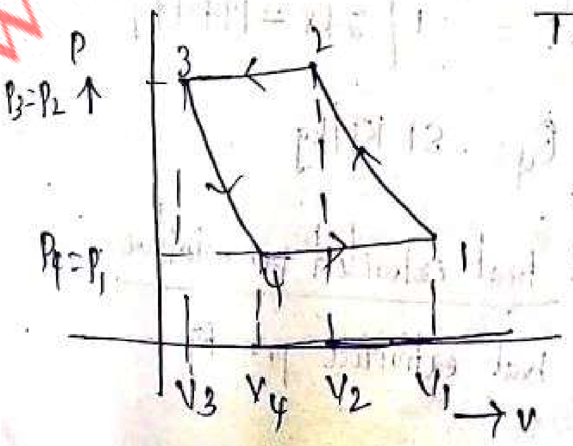
$$= 41$$

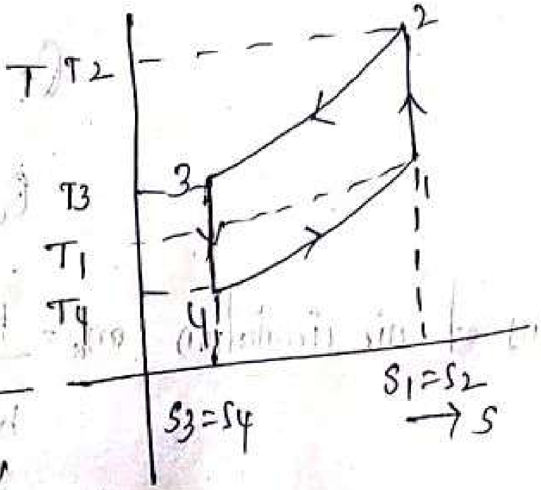
i) $$C.O.P = \frac{\text{heat absorbed}}{\text{Work done}} = \frac{Q_s}{W_{net}}$$

$$= \frac{C_p(T_1 - T_4)}{41} = \frac{1(268 - 219.45)}{41}$$

$$(C.O.P)_R = \underline{1.18}$$

③. A dense closed cycle refrigeration system working between 4 bar and 16 bar and extracts 126 MJ of heat per hour The air enter the compressor at 5°c and into the expander at 20°c Assume the unit runs at 300 rpm, find 1. power required to run the unit. 2. bore of the compressor 3. refrigerating capacity in tons of ~~ice~~ ice at 0°c per day. the Compressor and expander are double acting and stroke for Compressor and expander 300 mm, $\eta_{mech} = 80\%$ $\eta_{Turbine} = 85\%$. Assume This process is isentropic process





Given

$P_1 = P_4 = 4$ bar

$P_3 = P_2 = 16$ bar

$T_1 = 5°C = 273+5 = 278$ K

$T_3 = 20°C = 20+273 = 293$ K

Isentropic process, process 1-2.

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

$$T_2 = 278\left[\frac{16}{4}\right]^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_2 = 413.10 \text{ K}}$$

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

$$T_4 = 197.17$$

Heat extracted per kg of air Q_a (or) $Q_s = C_p \times (T_1 - T_4)$

$C_p = 1.005 / 1$

$$Q_s = 1[278 - 197.17]$$

$$Q_y = 81 \text{ kJ/kg}$$

Mass of air circulation $m_a = \frac{\text{heat extracted per minute}}{\text{heat extracted per kg}}$

= ~~2,000 kg/min~~

$$= \frac{2{,}100 \text{ kg/min}}{81}$$

$m_a = 25.92$ kg/min

W.D for compression process 1-2 per kg of air

$$W_c = \frac{\frac{\gamma}{\gamma-1} \times R \times [T_2 - T_1]}{0.8}$$

$\gamma = 1.4$

$R = 0.287$

= ~~[illegible]~~ 169.625

W.D for expansion process 3-4 per kg of air

$$W_t = ~~[illegible]~~ \times \frac{\frac{\gamma}{\gamma-1} \times R \times (T_3 - T_4)}{0.85}$$

= ~~[illegible]~~ 85

net W.D $W_{net} = W_c - W_e$

= ~~[illegible]~~ 84.62

1. power required to run the system $= m_a \times \frac{W_{net}}{60}$

$$= 25 \times \frac{84.62}{60}$$

= 35.35

2. Bore of compressor (D) = ?

⇒ mass of air supplied to the compressor at 1 is m_a.

= 25.12 kg/min [illegible] volume generally

PV = mRT at 1 with air $P_1V_1 = m_a R \cdot T_1$

$$V_1 = \frac{\overset{287}{\cancel{0.287}} \times 298 \times 25.12}{4}$$

1 J = 0.287 KJ/kg k.

= 287 J/kg k

$$\boxed{V_1 = 517.01 \times 10^3}$$

$$V_1 = \underline{\underline{5.17}}$$

Generally we know the volume $V = \frac{\pi}{4} d^2 \times l$ But here.

For double acting $= \frac{\pi}{4} \times d^2 \times l \times 2$

$$\boxed{V_1 = \left(2 \times \frac{\pi}{4} \times d^2 \times l\right) n}$$

$$5.17 = \left[2 \times \frac{\pi}{4} \times d^2 \times 330\right] \times 300$$

d = 0.192 m

d = 192 mm

Refegerating capacity at 0°c in tons of ice per day

= 126 MJ

$$= \frac{126 \times 10^3}{24} = 3024 \times 10^3$$

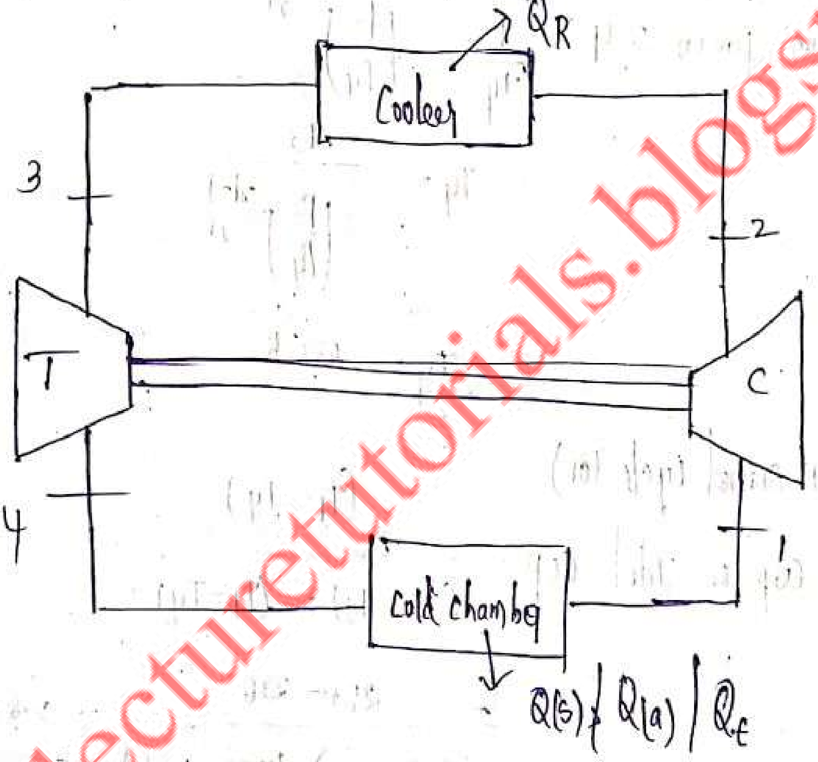
1 ton of refegeration = [illegible]

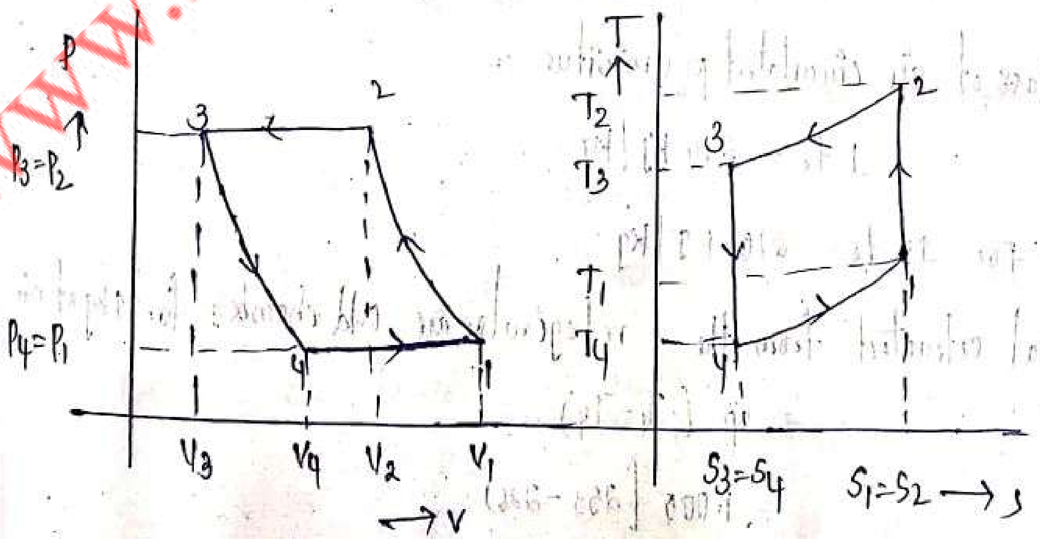
latent heat of ice 335 KJ/kg Then ice formation

capacity/day is $= 3024 \times 10^3 / 335 = 9026.86 = 9.12t$

Mech

A dense air Machine operating on reversed braytoncycle or Joule cycle or Carnot cycle and is required for a capacity of 10 tr the Cooler pressure 4.2 bar and the refrigeration pressure is 1.4 bar The air is cooled in the Cooler at Temp of 50°c and The Temp of air at inlet to the Compressor is -20°c determine for the idlecycle (i) C.O.P (ii) Mass of air circulated per minitue (iii) theoritical piston displacement of the compressor. (iv) Theoritical displacement of expander (v) net power per toune of refegeration show the cycle on pv Ts diagr





$Q = mf$

$T_3 = 50+273 = 323\ K$

$P_2 = P_3 = 4.2$ bar

$T_1 = -20°C + 273 = 253\ K$

$P_1 = P_4 = 1.4$ bar

i) C.O.P :- for compressor process $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

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

$$T_2 = 346\ K$$

For expansion process 3-4 $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

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

$$T_4 = 236\ K$$

Cop of bell carnot cycle (or)

theoritical cop or Idel cop $= \frac{(T_1 - T_4)}{(T_2 - T_3) - (T_1 - T_4)}$

$$= \frac{253 - 236}{(346-323)-(253-236)} = \underline{\underline{2.83}}$$

ii) Mass of air circulated per minitue :-

$1\ tr = 210\ KJ/kg$

For $10\ tr = 2100\ KJ/kg$

Heat extracted from the refegirator ~~ae~~ cold chamber for 1kg of air

$$= c_p\,(T_1 - T_4)$$

$$= 1.005\,[253 - 236]$$

$$= 17.005\ KJ/kg$$

Mass of air circulation per minute = heat extracted per minute / heat extracted per kg

$$= \frac{2100 \text{ KJ/min}}{17} = 123.4 \text{ KJ/min}$$

(iii) theoritical displacement of compressor

V_1 = theoritical displacement of compressor per minute

$PV = mRT$

$P_1V_1 = m_aRT_1$

$1.4 \times V_1 = 123.4 \times 287 \times 253$

$V_1 = 64 \text{ m3}$

1 bar = 10^5 N/mm²

R = 287 J/kg K

(iv) theoritical displacement of expander (V_4)

for constant pressure process 4-1 $\frac{V}{T} = C$

$$\frac{V_4}{T_4} = \frac{V_1}{T_1}$$

$$V_4 = T_4 \times \frac{V_1}{T_1} = 236 \times \frac{64}{25}$$

$$= 59.74 \text{ m}^3$$

(v) net power for tounne of refrigerator

net work done $= W_c - W_E \Rightarrow m_a \times c_p \times$ (heat rejected − heat extracted)

$$= 123.4 \times 1.005 \left[(T_2 - T_3) - (T_1 - T_4)\right]$$

= ~~123~~·741 KJ/min

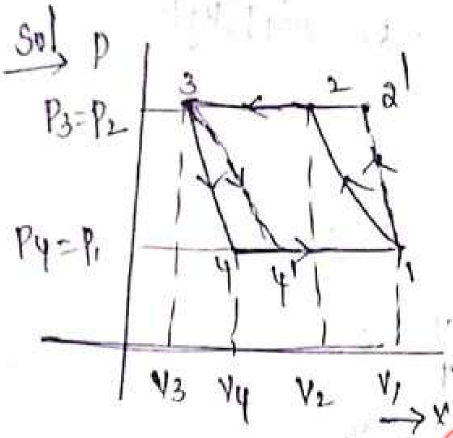
net power of the refrigerating Machine $P = \frac{741}{60} = 12.35$ KW

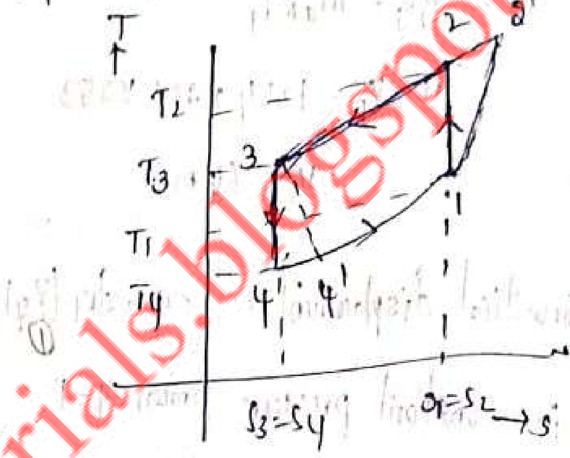
net power done tounne of refrigerator $= \frac{12.35}{10}$

$= 1.235$ KW

① A dense air refrigeration system operating between the pressure of 4 bar and 16 bar the air temp after heat rejection [cooling process] to the surrounding air 37°c. and the air Temperature at the exist of refrigerator is [cold chamber] 7°c The isentropic efficiencies of the Turbine and compressor are 0.85 and 0.8 Determine the compressor and turbine work per Tr, COP, power per Tr, Take $\gamma = 1.4$, $c_p = 1.005$ kJ/kg k

Sol





Given $P_1 = P_4 = 4$ bar ; $T_1 = 7°c + 273 = 280$ k.

$P_3 = P_2 = 16$ bar ; $T_3 = 37°c + 273 = 310$ k.

efficiency of Turbine $\eta_T = 0.85$, $\eta_c = 0.8$

$c_p = 1.005$ (or) 1 , $\gamma = 1.4$

process 1-2. Isentropic compression process.

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

$$\boxed{T_2 = 416 \text{ k}}$$

process Isentropic expansion 3-4

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

$T_4 = 208.61$ k

T_2' – Actual Temp of air leaving the compressor

T_4' – Actual Temp of air leaving the Turbine / expander

Note Isentropic efficiency of the Compressor. η_c =

~~Isentropic~~ Isentropic

$$= \frac{\text{Isentropic Increased Temperature}}{\text{Actual Increase in Temperature}} \Rightarrow \frac{T_2 - T_1}{T_2' - T_1}$$

$$0.8 = \frac{416 - 280}{T_2' - 280}$$

$$\boxed{T_2' = 450\ K}$$

→ Isentropic efficiency of Turbine, $\eta_T = \frac{\text{Actual Increase in Temp}}{\text{Isentropic Increase in Temp}}$

$$\eta_T = \frac{T_3 - T_4'}{T_3 - T_4}$$

$$0.85 = \frac{310 - T_4'}{310 - 208.61}$$

$$\boxed{T_4' = 223.8\ K}$$

→ Heat extracted from the refrigerator / refrigeration effect / heat absorb

$$= C_p \times [T_1 - T_4']$$

$$= 1\ (280 - 223.8) = 56.48\ KJ/kg$$

Mass of air per TR per minitue. Then $m_a = \frac{\text{heat extracted in KJ/min}}{\text{Heat extracted in KJ/Kg}}$

$$m_a = \frac{210}{56.48} \Rightarrow 3.71\ kg/min$$

Compressor work per Tr =

$$W_c = m_a \times c_p \times (T_2' - T_1)$$

$$= 635.6 \text{ kJ/min}$$

Turbine work per Tr =

$$W_T = m_a \times c_p \times [T_3 - T_4']$$

$$= 322.3 \text{ kJ/min}$$

→ $$C.O.P = \frac{\text{heat extracted per min}}{\text{net work done.}}$$

net work done = $W_c - W_e$

$$= 635.6 - 322.3$$

$$W_{net} = 313.3 \text{ kJ/min}$$

$$C.O.P = \frac{210}{313.3} = 0.67.$$

→ power per Tr $= \frac{\text{Work done}}{60}$

$$= \frac{313.3}{60} = \underline{\underline{5.22 \text{ kW}}}$$

Air refrigeration systems for aircrafts

1)(a) simple air cooling system

(b) simple air evaporization cooling systems

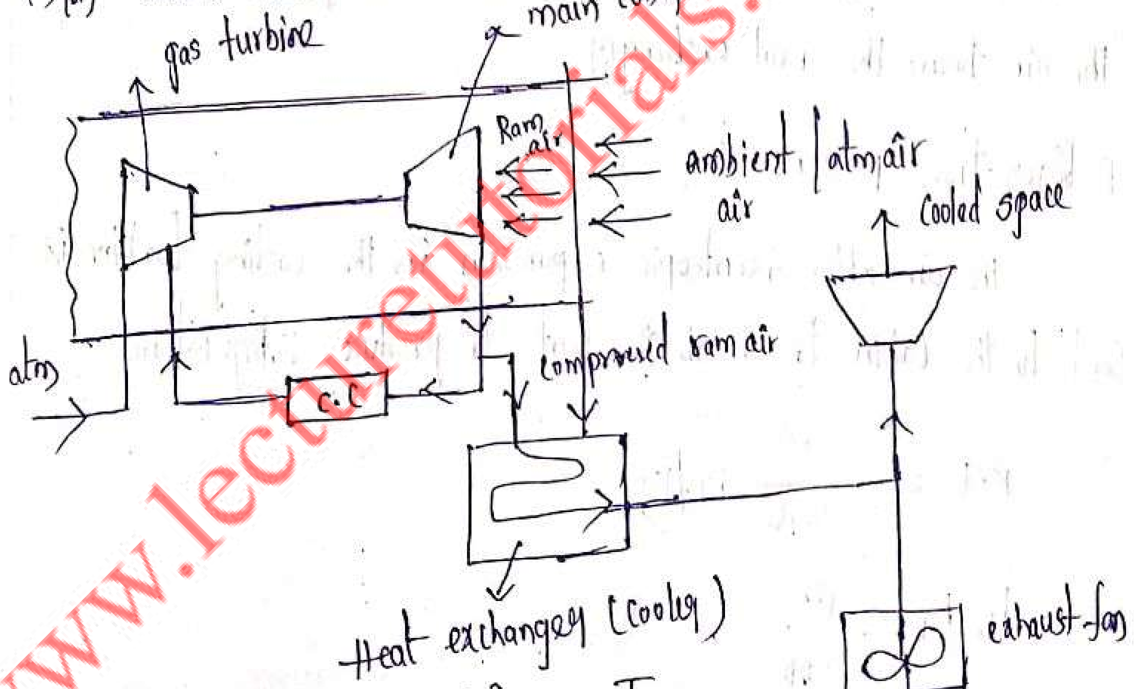
2)(a) Boot strap air cooling system

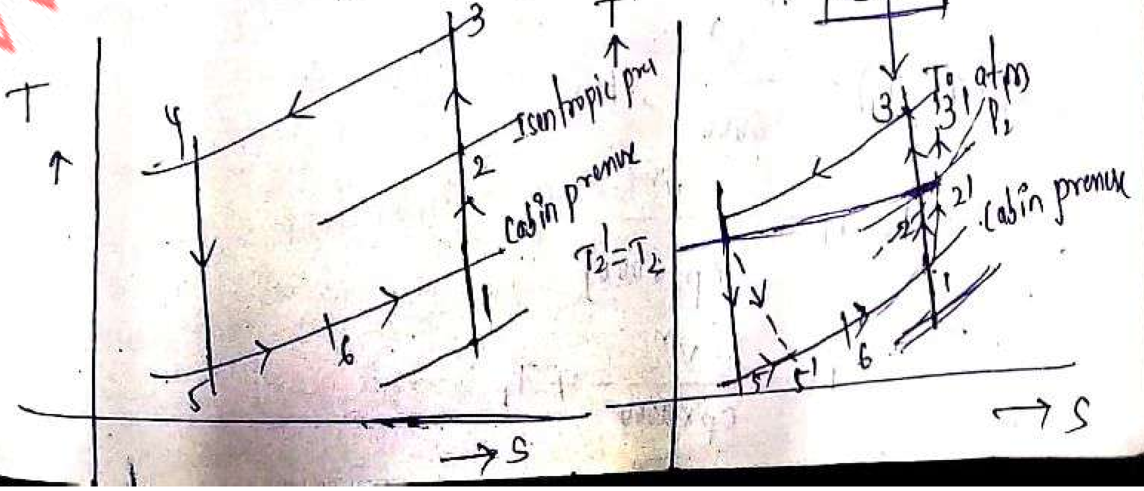
~~(b) Boot strap air evaporating cooling system~~

3) Reduced ambient air cooling system

~~4) Regenerative air cooling system~~

(1)(a) simple air cooling system —





Raming process – 1-2

Atm P_1 and T_1 is ramed isentropically P_2

Compression process – 2-3

Air compressed from P_2, T_2 to P_3, T_3

Cooling process – 3-4

Compressed air is cooled in the heat exchanger by the ramed air

Expansion process – 4-5

The cooled air is expanded isentropically in the cooling turbine. This turbine work is used to drive the cooling fan which draws the air from the heat exchanger.

Refrigeration process –

The air after isentropic expansion in the cooling turbine is sent to the cabin to absorb the heat to produce refrigeration.

$$K.E = \frac{V^2}{2000} \text{ kJ/kg}$$

$$h_2 - h_1 = \frac{V^2}{2000},$$

$$C_p(T_2 - T_1) = \frac{V^2}{2000}, \text{ Then}$$

$$T_2 - T_1 = \frac{V^2}{C_p[2000]}$$

$$T_2 = \frac{V^2}{C_p \times 2000} + T_1$$

$$\frac{T_2'}{T_1} = 1 + \frac{V^2}{2000\, C_p \cdot T_1}$$

$$\frac{T_2'}{T_1} = 1 + \frac{V^2}{2000\, C_p\, T_1}$$

$C_p - C_v = R$

$\frac{C_p}{C_v} = \gamma$

$$\frac{T_2'}{T_1} = 1 + \frac{V^2(\gamma-1)}{2000\, C_p\, \gamma R\, T_1}$$

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

If Kinetic energy is to be Taken in Joule's Then velocity changes as

$$\frac{T_2}{T_1} = 1 + \frac{V^2(\gamma-1)}{2 \cdot \gamma R T_1}$$

Where a - Sonic velocity of ambient air $a = \sqrt{\gamma R T}$ is sonic velocity of ambient air

V - aircraft velocity Then

match Number $M = \frac{V}{a} = \frac{\text{air craft velocity}}{\text{Sonic air velocity}}$

$$\frac{T_2}{T_1} = 1 + \frac{V^2(\gamma-1)}{2a^2} = 1 + \frac{V^2}{a^2}\,\frac{\gamma-1}{2}$$

$$\boxed{\frac{T_2}{T_1} = 1 + M^2\left(\frac{\gamma-1}{2}\right)}$$

→ Consider process 2-3

Work done in compression $W_c = m \cdot C_p (T_3 - T_2)$

→ process 3-4

heat rejection in heat exchanger $Q_R = m \cdot C_p \left[T_3 - T_4\right]$

→ process 4-5

Work done in Turbine $W_T = m\, C_p \left[T_4 - T_5\right]$

Re-frigeration effect = [illegible]

T_6 is the incide Temp of cabin

Refrigeration effect $N = m \cdot c_p [T_6 - T_5]$

Then c.o.p of Idle cycle $= \frac{N}{W_c} = \frac{\cancel{m} \cancel{c_p} [T_6 - T_5]}{\cancel{m} \cancel{c_p} [T_3 - T_4]}$

$$\boxed{C.O.P_i = \frac{T_6 - T_5}{T_3 - T_4}}$$

With composition of actual cycle

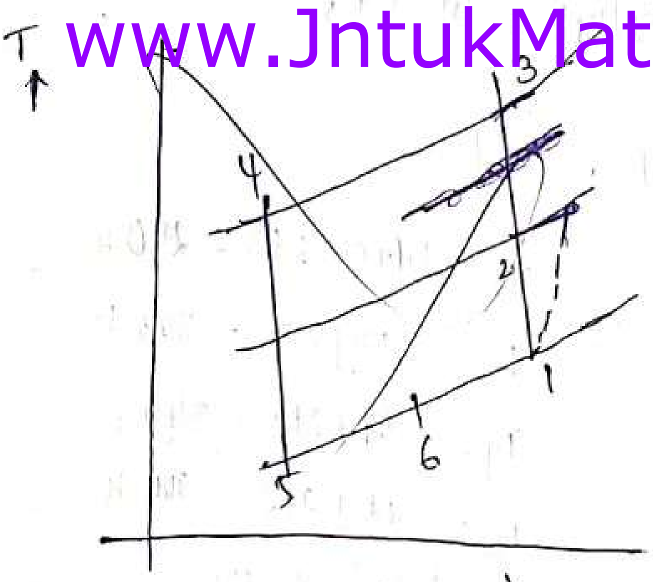
Ram efficiency $= \frac{\text{actual pressure raise}}{\text{Isentropic pressure raise}} = \cancel{\frac{P_1 - P_2'}{P_1 - P_2'}} \quad \frac{P_{2'}-1}{P_2-1}$

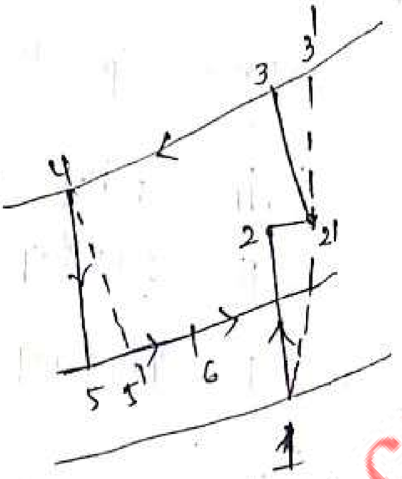
Compressor efficiency $= \frac{\text{Isentropic work}}{\text{actual work}} \eta_c = \frac{h_3 - h_2'}{h_3' - h_2'}$

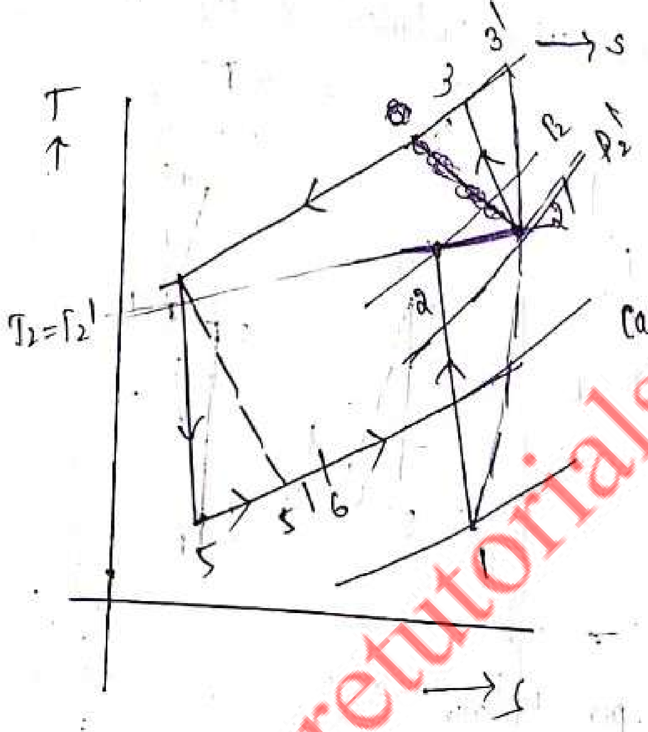
$$\eta_c = \frac{T_3 - T_2'}{T_3' - T_2'}$$

Turbine efficiency $\Rightarrow \eta_T = \frac{\text{Actual Work}}{\text{Isentropic work}} = \frac{T_4 - T_5'}{T_4 - T_5}$

$$= \frac{h_4 - h_5'}{h_4 - h_5}$$







$\cancel{\frac{P_2'-P_1}{P_2-P_1}}$

① An aircraft refrigeration plant as to handle a cabin load of 30 tonnes the atm Temp is 17°c The atm air is compressed to a Pressure of 0.95 bar and Temp of 30°c due to ram action The air is then further compressed in a compressor to 4.75 bar, cooled in the heat exchanger to 67°c, expanded in a Turbine to 1 bar pressure and supply to the cabin The air leaves the cabin at a Temp of 27°c the isentropic efficiency of Compressor & Turbine is 0.9 caluculate the Mass of air circulate per miniute

Find COP, $c_p = 1.004$ kJ/kgK, $\gamma = 1.4$

Sol → Given $c_p = 1.004$, $\gamma = 1.4$

$P_1 = 1$ bar $T_1 = 17°C + 273 = 290$ K

$P_2 = 0.95$ bar $T_2 = 30 + 273 = 303$ K

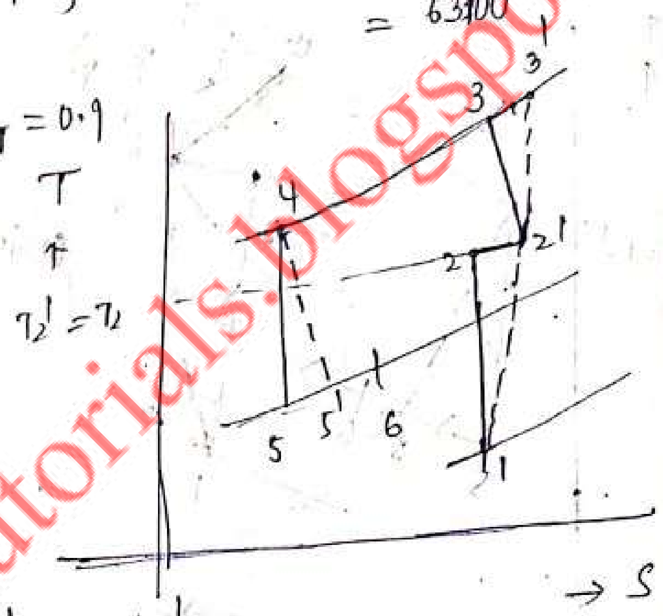
$P_3 = 4.75$ bar $T_4 = 67 + 273 = 340$ K

$T_6 = 27 + 273 = 300$ K

1 Tr = 210 kJ/min Then 30 tons = 30×210

= 6300

$\eta_C = \eta_T = 0.9$



$$m_a = \frac{\text{heat extracted per kJ/min}}{\text{heat extracted in kJ/kg}}$$

= 6300

→ heat extracted in kg = refrigeration effect ~~$m \times (T_6 - T_5)$~~

$N = [T_6 - T_5]\, m \times c_p$

For Isentropic Compression process $\frac{T_3}{T_2} = \left[\frac{P_3}{P_2}\right]^{\frac{\gamma-1}{\gamma}}$

$T_3 = 480$ K.

Efficiency $\eta_c = \frac{T_3 - T_2}{T_3' - T_2'} , \Rightarrow \frac{T_3 - T_2}{T_3' - T_2}$

$$0.9 = \frac{480 - 303}{T_3' - 303}$$

$$T_3' = 499.7 \text{ k}$$

$W_c = m.cp \left[T_3' - T_2 \right] \Rightarrow 1.004 \times 1 \left[499.7 - 303 \right]$

$$W_c = 196.97 \approx 197.$$

Isentoopic expansion $\frac{T_4}{T_5} = \left[\frac{P_4}{P_5} \right]^{\frac{\gamma-1}{\gamma}}$

$$P_5 = \frac{\cancel{340}}{\;} \quad 217.2 \text{ K}$$

$$\eta_T = \frac{T_4 - T_5'}{T_4 - T_5}$$

$$0.9 = \frac{340 - T_5'}{340 - 217.2}$$

$$T_5' = 230 \text{ K}$$

refrigeration effect $N = cp \left[T_6 - T_5' \right]$

$$N = 70.28 \text{ KJ/kg}$$

Then $m_a = \frac{6300}{70.28} = 89.64$ kg/min

$c.o.p = \frac{N}{W_c} = \frac{70.28}{197} = 0.356$

② The cockpit of a jet plane flying at a speed of 1200 km/hour. is to be cooled by simple air cooling system the cockpit is to be Maintained at 25°c (Cockpit = cabin) and the pressure in the Cockpit is the ambient Pr and Temp are 0.15 bar and 30°C

Cock pit cooling load = 10TR

main compression ratio = 4

Ram efficiency = 90%

Temperature of air leaving the heat exchanger and entering the Cooling Turbine (T_4) = 60°c

pressure drop in the heat exchanger = 0.5 bar

pressure loss b/w the cooler turbine and the Cock pit = 0.2 bar

Assume isentropic efficiency of main Compressor, Turbine as = 80%.

$\gamma = 1.4$, $C_p = 1$ kJ/kg k. find cop and

Sol

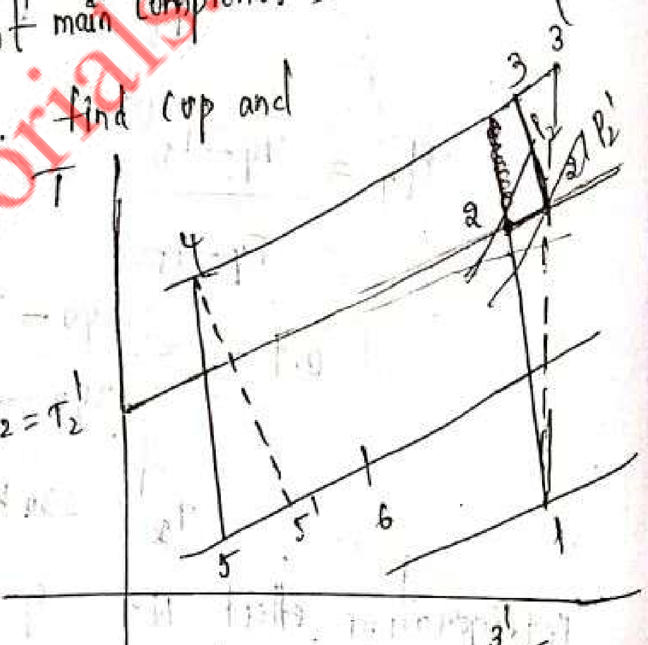
$P_2 > P_2'$

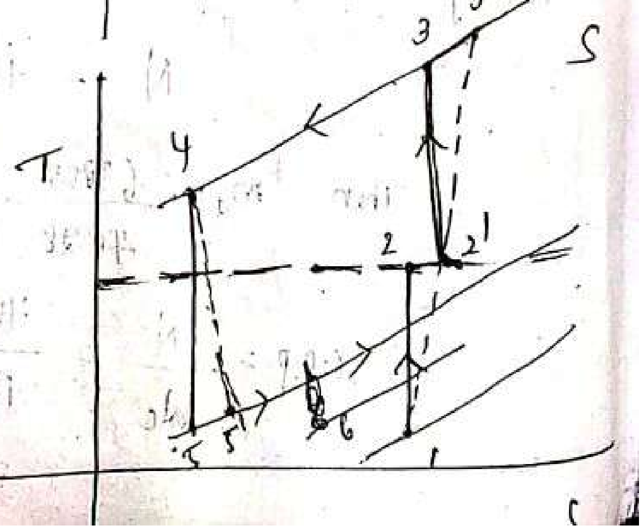
$T_2 = T_2'$

Given

Speed V = 1200 KM/hour

= 111.14 m/sec





$T_6 = 25° + 273 = 298$

$P_6 = 1$ bar

$T_1 = 30 + 273 = 303$ K

T =

cooling load = 10x210 = 2100 kJ/min

main compressing ratio $\frac{P_3'}{P_2'} = 4 = \frac{P_3}{P_2}$

Ram efficiency $= 90\% = 0.9$

$T_4 = 60^\circ + 273 = 333\ k$

$P_4 = P_3 - 0.5 \times P_4$ $\qquad P_5 = P_5'$

$P_5' - P_6 = 0.2$

Where ~~P_5~~ $P_5' = P_6 + 0.2$

$P_5' = 1.2$

$\eta_c = \eta_T = 0.8$

$\rightarrow$ $T_2 = T_2' = T_1 + \frac{V^2}{2000 \times C_p}$

$T_2 = T_2' = 303 + \frac{111.14}{2000 \times 1} = 358.5\ K$

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

$P_2 =$ ~~P_2~~ $= P_1 \left(\frac{T_2}{T_1}\right)^{\frac{\gamma-1}{\gamma}} = 1.53$ bar

$\eta_R = \frac{\text{Actual Pressure raise}}{\text{Isentropic pressure raise}} = \frac{P_2' - P_1}{P_2 - P_1}$

$0.9 =$ [illegible]

$P_2' = 1.46$ bar

Isentropic process 2-3

$$\frac{T_3}{T_2'} = \left[\frac{P_3}{P_2'}\right]^{\frac{\gamma-1}{\gamma}}$$

$$T_3 = T_2'\left[\frac{P_3}{P_2'}\right]^{\frac{\gamma-1}{\gamma}} = 532.7\ k$$

Isentropic efficiency of compressor $[\eta_c] = \frac{\text{Isentropic Temp rise}}{\text{Actual Temp rise}}$

$$0.8 = \frac{T_3 - T_2'}{T_3' - T_2'}$$

$$T_3' = 576\ k.$$

$P_3 = P_3'$

Main compressor pressure ratio $\frac{P_3}{P_2'} = 4$

$$P_3' = 4 \times P_2' = 5.84\ \text{bar}$$

pressure drop in heat exchanger = 0.5 bar Then

$$P_4 = P_3' - 0.5$$

$$P_4 = 5.34\ \text{bar}$$

pressure loss 0.2 bar b/w Turbine and cockpit.

pressure of the air leaving the cooling turbine $P_5 = P_5' = P_6 + 0.2$

$$P_5 = P_5' = 1.2\ \text{bar}$$

Isentropic process 4-5 $\cancel{\left[\frac{T_4}{T_5}\right]^{\frac{\gamma-1}{\gamma}} \left(\frac{P_4}{P_5}\right)}$

$$\frac{T_4}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_5 = 217.6\,K$$

Isentropic efficiency of cooling turbine $\eta_T = \frac{\text{Actual Temp raise}}{\text{Isentropic Temp raise}}$

$$0.8 = \frac{T_4 - T_5'}{T_4 - T_5}$$

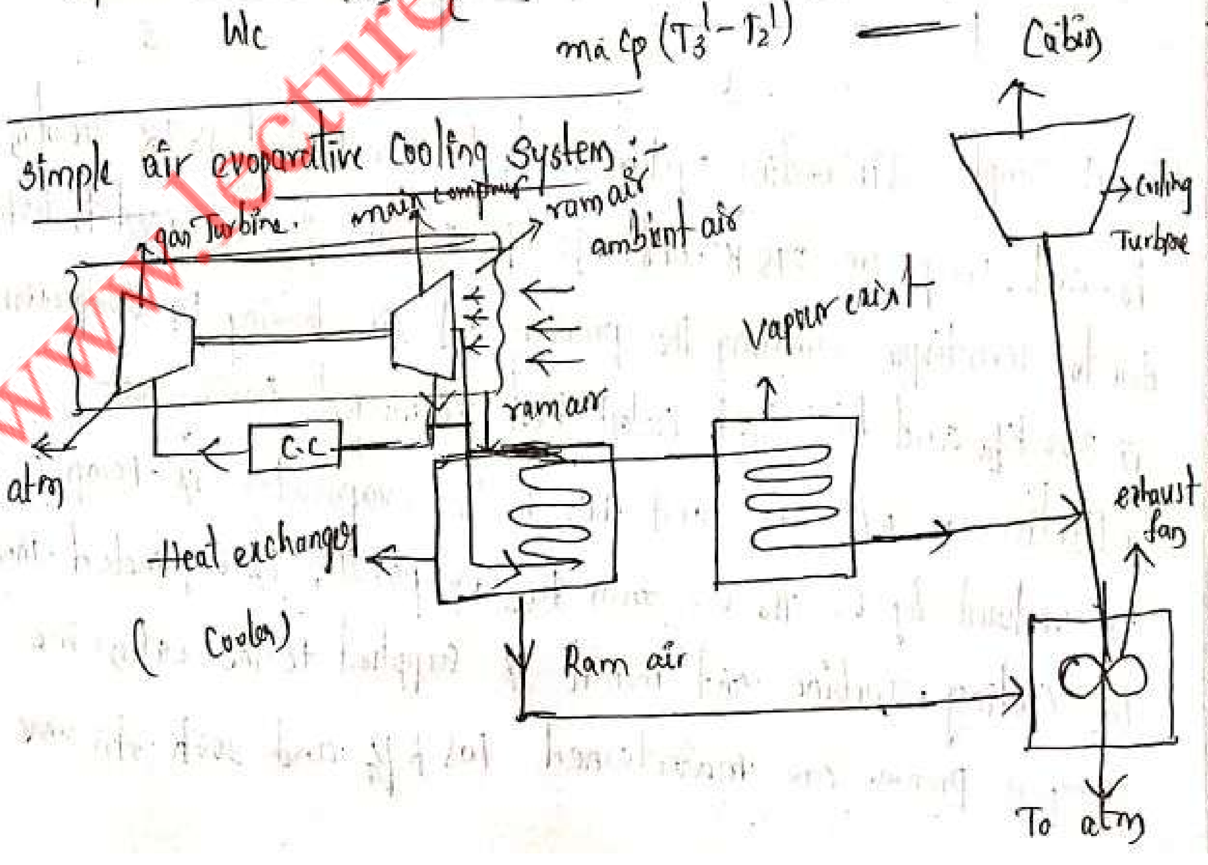
$$T_5' = 240.7\,K.$$

Mass of air $m_a = \frac{\text{heat extracted in min}}{\text{heat extracted in kg}}$

$$= \frac{210 \times 10}{c_p(T_6 - T_5')} = 36.6\ \text{kg/min}$$

$$COP = \frac{210\,Q}{W_c} \text{ (or) } \frac{N}{C} = \frac{210 \times 10}{m_a c_p (T_3' - T_2')} = \underline{0.264}$$

Simple air evaporative cooling system :-

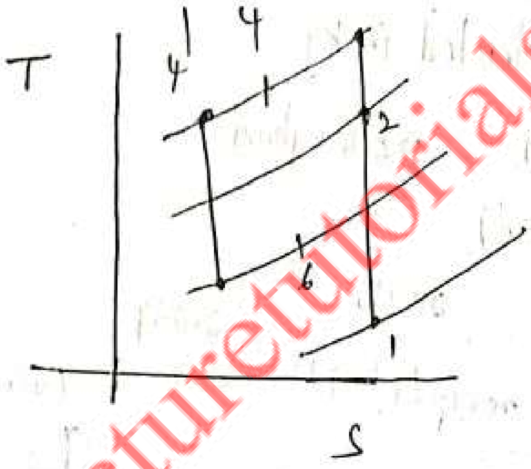


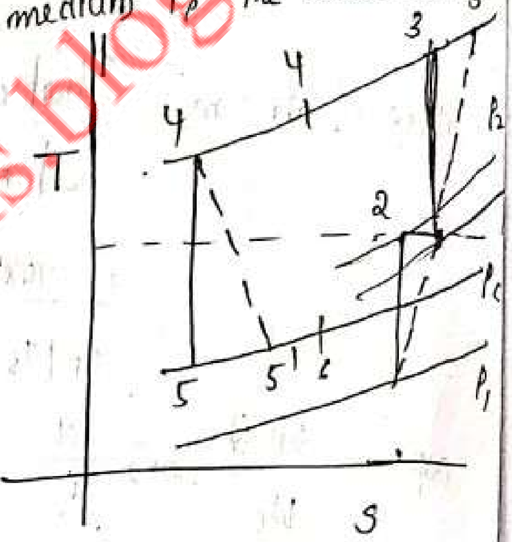
further cooled in the evaporator before expanding in the Cooling Turbine in evoparator additional cooling effect is produced by evaporation of liquid refregent such as Water, at high altitudes alchol or ammonia are used as refregerent.

→ Suppose 20,000 m height water boiling at 40°c alochol at at 9°c ammonia at 70°c

→ A part of high Pr and high Temp of air is first Compressed main Compressor Cooled in The heat exchanger which is

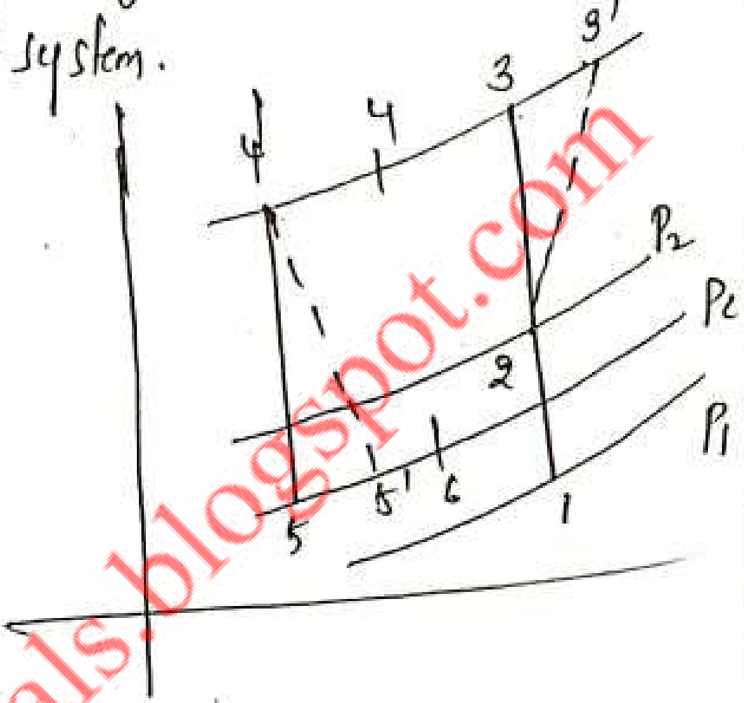
→ In heat exchanger The cooling medium is the ramed air





① A Simple Air Cooling systems is to be the load of 15 TR the dry Pr. and Temp are 295 K and 90 KPa The air Pr. increased to 100KPa due to isentropic ramming the pressure of air leaving the Compressor is 350 KPa and his first cooled heat exchanged having the effectiveness of 0.65 and then in the evaporater is Temp is reduced by 6°C The air from the evaporater is expanded Through the cooling Turbine and Then it is supplied to The Cabin where Temp & Pressure are maintained 105 KPa and 300K. Assume

Ex Isentropic efficiency of compressor of Turbine are 80% & 75%. find the Mass of air Passing Through The cabin. power required for the system, Cop of system.



Sol →

1 TR = 210 kg/min

= 15×210

$T_1 = 295\,K$; $P_1 = 90\,kPa$

$T_2 = 100\,kPa$; $P_3 = 350\,kPa$

efficiency $E = \frac{T_3' - T_4}{T_3' - T_2}$

$T_4' = 6°C$

$T_6 = 300\,K$

$P_6 = 105\,kPa$

power required P = Work of compression $\Rightarrow W_c = \frac{C_p(T_3' - T_2)}{60} \times m_a$