



THERMAL

$$F = ma$$

$$F = \frac{mg}{g_c}$$

$\frac{1}{g_c}$ = proportionality constⁿ

g_c = universal constant

weight of body

$$W = \frac{mg}{g_c}$$

$$g_c = 9.81 \frac{\text{m}}{\text{kg} \cdot \text{s}^2} \text{ or } g_c = 1 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2}$$

weight of body vary place to place

mass of body does not vary place to place.

Specific volume : It is defined as volume per unit mass.

$$s.v. = \frac{\text{volume}}{\text{mass}} \left(\frac{\text{m}^3}{\text{kg}} \right)$$

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \left(\frac{\text{kg}}{\text{m}^3} \right)$$

$$\boxed{R.V. = 1}$$

Density is reciprocal of specific volume and specific volume is reciprocal of density.

Relative density or specific gravity :

It is defined as ratio of density of substance to density of water.

$$\rho_{\text{water}} = 1 \text{ gm/cc} = 1000 \text{ kg/m}^3$$

pressure : It is defined as force per unit area.

$$p = \frac{\text{Force}}{\text{Area}} \left(\frac{\text{N}}{\text{m}^2} \right) \text{ or pascal.}$$

pascal is very small unit of pressure hence we using kpa and mpa higher units of pressure.

$$F = 1 \text{ kgf}$$

$$m = 1 \text{ kg}$$

$$a = 9.81 \text{ m/s}^2$$

$$1 \text{ kgf} = \frac{1 \text{ kg} \times 9.81 \text{ m/s}^2}{g_c}$$

$$g_c = 9.81 \frac{\text{kg} \cdot \text{m}}{\text{kgf} \cdot \text{s}^2} = \text{m.k.s.}$$

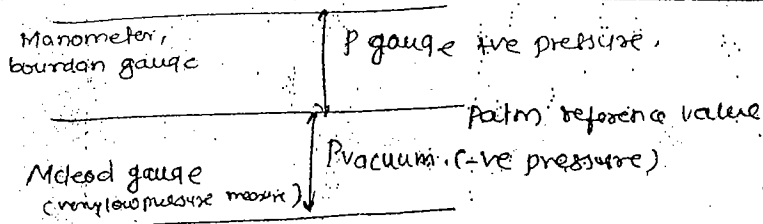
$$1 \text{ kgf} = 9.81 \text{ N}$$

$$g_c = \frac{9.81 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2}}{9.81}$$

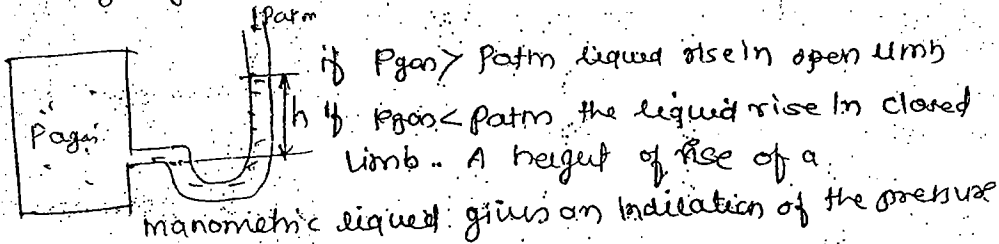
$$= 1 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2} \text{ (SI)}$$

$$P_{abs} = P_{atm} + P_{gauge}$$

$$P_{abs} = P_{atm} - P_{vacuum}$$



closed gauge barometer on Boyle's Law.



$$P_{abs} = P_{atm} + P_g$$

$$= P_{atm} + \frac{\rho g h}{\rho_c}$$

$$P_{abs} = P_{atm} - P_{vacuum}$$

$$= P_{atm} - \frac{\rho g h}{\rho_c}$$

$$1 P_{atm} = 101.325 \text{ kPa} = 760 \text{ mm of Hg column}$$

$$= 76 \text{ cm of Hg column}$$

$$= 10.33 \text{ m of H}_2\text{O column}$$

$$1 \text{ torr} = 1 \text{ mm of Hg column}$$

$$= 133.33 \text{ Pa}$$

$$= 0.13333 \text{ kPa}$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa} = 752.6 \text{ mm of Hg column}$$

A rock is submerged in sea water at a depth of 40m
what is the pressure acting on the top of the rock

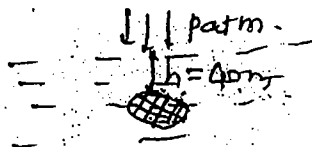
$$\Rightarrow P = \rho g h$$

$$\rho_{\text{sea water}} = 1100 \text{ kg/m}^3$$

$$P_{abs} = P_{atm} + P_{gauge}$$

$$= P_{atm} + \frac{\rho g h}{\rho_{\text{Hg}}}$$

$$= 101.325 + \frac{1100 \times 9.81 \times 40}{1000} = 532.64 \text{ kPa}$$



to
the
diff

→
press

ΔP

$$= \frac{30}{1000}$$

$$= 95.6$$

A pressure
the open
should be
withstanding
⇒

$$P_{atm} + P_g$$

Steam P
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mains.

⇒ For b

P_{steam}

P_{steam}

P_{steam}

P_{steam}

age
vacuum.

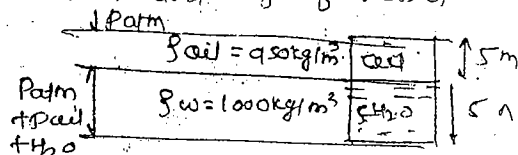
water is poured at a height 5m in cylindrical vessel above that oil of S.G 0.95 is poured for another 5m. what is difference in pressure acting on the bottom and top of vessel

⇒ pressure /n difference

$$\Delta P = P_{oil} + P_{water}$$

$$= \frac{\rho_o g h_o}{1000 \text{ gc}} + \frac{\rho_w g h_w}{1000 \text{ gc}} = \frac{950 \times 9.81 \times 5}{1000 \times 1} + \frac{1000 \times 9.81 \times 5}{1000 \times 1}$$

$$= 95.64 \text{ kPa}$$



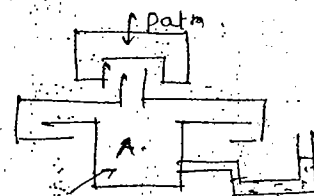
in 4m
in closed
the pressure

A pressure cooker is designed for a pressure of 1 bar gauge. the opening available in the head of cooker is 4 mm^2 . what should be weight that should be kept above with that withstand the pressure

$$\Rightarrow P_{atm} + P_{gauge} = P_{atm} + \frac{m g}{A}$$

$$105 = \frac{m \times 9.81}{4 \times 10^{-6}}$$

$$m = 40.9 \text{ gm}$$



$$P_{inside} = P_{external}$$

$$P_{atm} + \frac{m g}{A} = P_{atm} + \frac{m g}{A}$$

urn.

Steam is flowing in the main pipeline and a manometer is connected with mercury. as the manometric liquid, which has a density of 13600 kg/m^3 , what is the pressure of steam in the main.

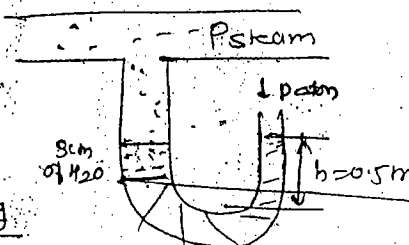
⇒ For balance

$$P_{steam} + P_{H_2O} = P_{atm} + P_{Hg}$$

$$P_{steam} + \frac{\rho_w \cdot g \cdot h_w}{1000 \text{ gc}} = P_{atm} + \frac{\rho_{Hg} \cdot g \cdot h_{Hg}}{1000 \text{ gc}}$$

$$P_{steam} + \frac{1000 \times 9.81 \times 3 \times 10^{-2}}{1000 \times 1} = \frac{101325}{1000 \times 1} + \frac{13600 \times 9.81 \times 0.5}{1000 \times 1}$$

$$P_{steam} = 168 \text{ kPa}$$



m of Hg column

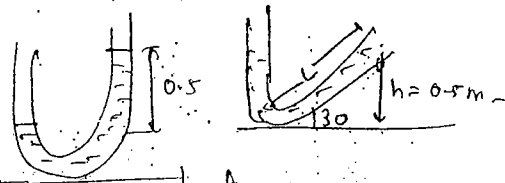
of 40m
rock

n.

m

The height of rise of mercury in a tube manometer it is replaced with inclined manometer which an angle of 30° up to what length the Hg should flow on inclined plane to measure the same pressure.

Ans ①



When a fluid of density of 2 gm/cc the height of rise is 0.2 m if it replaced with fluid of density 10 gm/cc what is height of rise.

$$\frac{h}{L} = \sin \theta$$

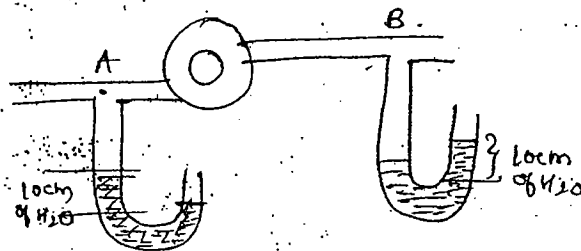
$$L = \frac{h}{\sin \theta} = \frac{0.5}{\sin 30} = 1$$

$$\Rightarrow h \propto \frac{1}{\rho} \quad \rho_1 h_1 = \rho_2 h_2$$

$$\Rightarrow 2 \times 10 = 2 \times 0.2 = 10 \times h_2$$

$$h_2 = 0.04 \text{ m}$$

Across a flow two manometer are connected as shown in the figure. what calculate difference in pressure in B and A in kPa.



$$\begin{aligned} P_B - P_A &= 10 - (-10) \\ &= 20 \text{ cm of H}_2\text{O} \\ &= 0.2 \text{ m of H}_2\text{O} \\ &= \frac{0.2}{10.23} \times 101.325 \\ &= 1.98 \text{ kPa} \end{aligned}$$

In thermodynamics we will be taking of system.

Open system: It is in this energy transaction interaction as well as mass interaction.

eg: water flow through pipe line.

When water is flow in pipe the mass crosses the system boundary as well as energy crosses the system boundary.

Closed sys

only en
eg: sun

Isolated sy

energy into
eg: coffee

Identify

① A fountain

② A candle

③ A balloon

④ A TV set

⑤ transfer

⑥ A car

⑦ A moon

A system

Separated

the environment

System

boundary

if external

ve.

if internal

ve.

if system

and vice versa

if h

if h

A system

form where

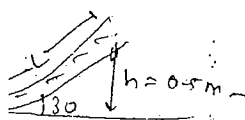
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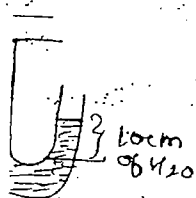
der it is
of 80°
plane to



in

$$\sin 30 = \frac{0.5}{s} \Rightarrow s = 1$$

as shown
in B



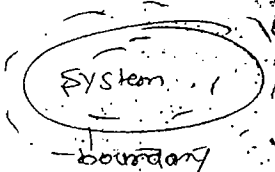
Closed system : Closed system is a system in which there is only energy interaction but no mass interaction.
eg. sun.

Isolated system : Isolated system in which there is neither energy interaction nor mass interaction.
eg. coffee in a thermoflask.

Identify to which category of following system belong.

- ① A fountain pen while writing - open system.
- ② A candle flame while burning - open system.
- ③ A biogas digester - open system.
- ④ A TV switched ON - closed system.
- ⑤ Transformer while working - closed system.
- ⑥ A.C railway coach - open system.
- ⑦ A moon in its orbit - closed system.

A system is defined as delimited volume which has been separated for the purpose of analysis. Observation and inference the envelope of system is called as boundary and volume



Surrounding is called as surrounding. If system volume expand the work is said to be done by the system and system work is $+$ ve. When system volume contract the work is said to be done on the system. the $+$ ve and $-$ ve work done is given in $-$ ve sign.

If external agent does work on system the work done is said to be $-$ ve.

$$W_{\text{system}} + W_{\text{surrounding}} = 0$$

If system does $+$ ve work the surrounding will do negative work and viceversa.

If heat is supplied to a system it is given $+$ ve sign.

If heat is withdrawal from a system it is given a $-$ ve sign.

A system will not take heat & work will only energy in different form. When energy system crosses boundary it may become heat or it may become work. Heat and work are path function they depend upon the path followed. Heat & work are inexact differential. Heat & work are transient in nature. Heat and work are boundary phenomenon.

$$Z = f(x, y)$$

$$dz = \left(\frac{dz}{dx} \right)_y dx + \left(\frac{dz}{dy} \right)_x dy$$

$$\left(\frac{\partial z}{\partial x} \right)_y = M ; \left(\frac{\partial z}{\partial y} \right)_x = N$$

$$dz = M dx + N dy$$

$$\frac{\partial M}{\partial y} = \frac{\partial}{\partial y} \left(\frac{\partial z}{\partial x} \right) = \frac{\partial^2 z}{\partial y \partial x}$$

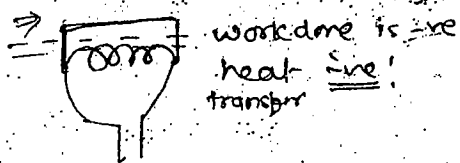
$$\frac{\partial N}{\partial x} = \frac{\partial}{\partial x} \left(\frac{\partial z}{\partial y} \right) = \frac{\partial^2 z}{\partial x \partial y}$$

$$\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x} \rightarrow \text{exact differential}$$

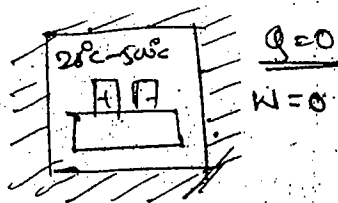
$$\frac{\partial M}{\partial y} \neq \frac{\partial N}{\partial x} \rightarrow \text{inexact differential}$$

* Identify the signs of heat & work interaction in the following cases.

- ① A heater coil is kept in flowing water and it is connected external mean. what are the sign of heat and work and cold water enters the system leaves as hot water

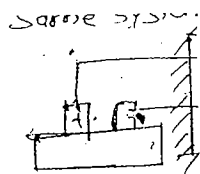


- ② In a insulated rigid cylinder a battery is kept across the terminals of battery a resistor is connected and temp of air is increases from 25°C to 50°C what are the signs of heat & work interaction

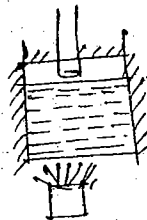


Exact differentials are path function they depend on the end state but do not depend upon path followed.

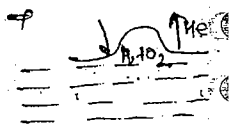
whereas inexact differentials are path functions and depend upon the path followed.



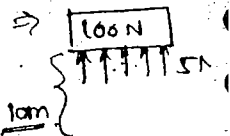
A piston cyl slides except friction a tell the free



hydraulic is ignited by mi water. work



A 100N mass drag across



A 1 kg mass the work

$$\Rightarrow W = 0$$

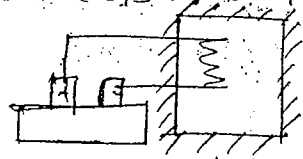
State

State thermodynamic two and pressure a

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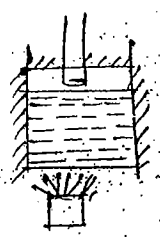
conditions are
depend
lowered.

Same system battery placed outside what are signs of W & Q

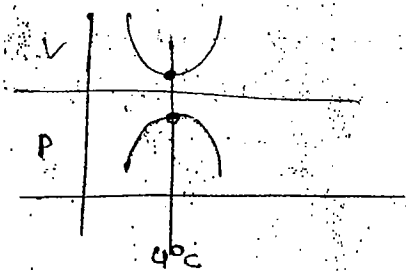


$\Rightarrow Q = 0$
 $W = +ve$

A piston cylinder mechanics water & ice are kept it is insulated all sides except the bottom. it is heated by means of flame and emission allows to move such that the pressure remain constant till the ice completely melts what are the sign of W and Q



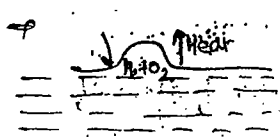
Q is +ve
 W is 0



The following

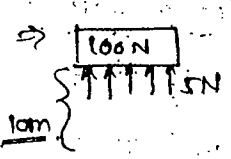
- S
- heat
- as hot water

hydrogen and oxygen in form of bubble for large time ignited by minute spark hydrogen and oxygen combined to form water. what are signs of W & Q



Q is +ve
 W zero (-ve)

A 100N mass falls freely in atmosphere overcoming atmospheric drag resistance of 5N by a distance of 10 m what is the work done



Work done = resistance force $\times$ distance travelled
 $= 5 \times 10 = 50$

A 1kg mass falls freely in vacuum by a distance of 1m what is the work done

$\Rightarrow W = 0$

State

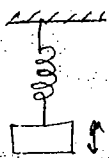
State of system is specified by certain specific thermodynamics coordinate minimum no. quadrant required are two and they should be independent nature like a pressure and volume. volume & temp, temp and pressure.

Change of state: If any one of the thermodynamic coordinates are both change then system is said to undergo a change of state.

processes: locus of series of change of state gives a process.

Types of processes:

Reversible process: It is a process which can be made to exactly retrace its path without suffering any deviation or losses. Any process without friction or losses can be called as reversible process. eg:



Electroplating: If anode is made cathode and cathode is made anode whatever material deposited can be redeposited back. So this is called to be reversible.

If water at 100°C is heated to steam at 100° by a flame of 100°C it is internally reversible and externally irreversible.

If water at 100°C is converted to steam at 100°C by using a flame of 100.01°C then it is internally reversible as well as externally reversible.

Irreversible: Any process that cannot be made to exactly retrace its path is called an irreversible process.

eg: combustion, water falling from top of a dam, sun's energy,

Any process with friction is irreversible process.

Extensive property:

Any property that depends on mass is called an extensive property.

eg: volume, enthalpy, internal energy, entropy, K.E, P.E etc.

Intensive

Any property

eg: speed, P

Specific heat

Specific volume

Specific energy

density is

Macroscopic

Macroscopic

① No assumption regarding matter

② Very few are required to define the state like pressure, volume, temp.

③ They can be measured

④ They can be sensed

Rate of area is a property, property, are same

Diathermic

Diathermic

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, PE etc.

Intensive property

Any property that is independent of mass is called an intensive property.

eg: speed, pressure, temp, velocity, accelⁿ, viscosity and any specific extensive property is an intensive property.
Specific volume, specific internal energy, specific enthalpy, specific entropy, specific K.E, specific P.E.
density is an intensive property.

Macroscopic & Microscopic approach

Macroscopic

① No assumption are made regarding structure of matter

② very few parameter are required to specify the state of system like pressure, volume, volume temp, temp & pressure.

③ They can easily be measured

④ They can be sensed by sense per substance

Microscopic

① In this matter is composed of molecule.

② Many parameters required to specified to state of system. i.e. $6 \times 6.023 \times 10^{23}$ coordinate are required.

③ they cannot be easily measured

④ They can not be sensed by sensed per substance.

Rate of change of molecule per of momentum per unit area is called pressure and pressure is microscopic property. microscopic property is leading to a macroscopic property. hence the approaches are different but conclusion are same.

Diatheirmic substance

diathermic substances are those substance which allows heat to pass through them. any good conductor of heat is called a diathermic substance.

eg steel, silver, copper etc.

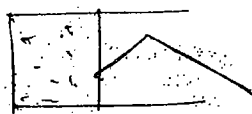
Adiabatic substance

are those substances which do not allow heat to pass to them

eg Asbestos, glass wool, cork, even asbestos

when two separate systems are in contact each other through a diathermic wall there is interaction between two systems and two systems achieved common thermodynamic coordinates which is called as state of thermal equilibrium. if two separate systems are in contact each other to a ~~adiabatic~~ adiabatic wall. there is no interaction between two systems and systems remain as they are.

Thermodynamic equilibrium



If there are no internal forces or external forces acting on system then the system is said to be in mechanical equilibrium. If temp across every section

is same then the system is said to be in thermal equilibrium. the chemical constitution are such that they are no exothermic reaction or endothermic reactions then the system is said to be a ~~ex~~ end chemical equilibrium.

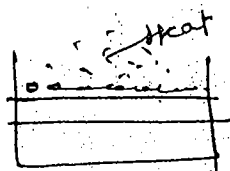
if system is in mechanical, thermal, chemical equilibrium is called thermodynamic equilibrium.

Quasistatic process (ideal process)

It is an ideal process is very very slow process

if a system is made to undergo a series of change of state such that it is in

thermodynamic equilibrium at each and every state then the locus of all the states is called as quasistatic process. quasistatic process is ideal process which can never exist in reality.

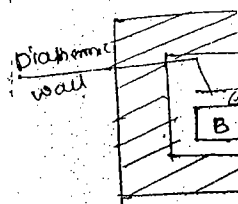


and grains allows to form fall one after another on piston cylinder arrangement. then moment of such a piston is called as quasistatic process.

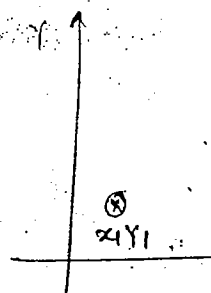
A series of infinitesimal no



Zerth



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If we find thermal eq then locu

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① Liquid

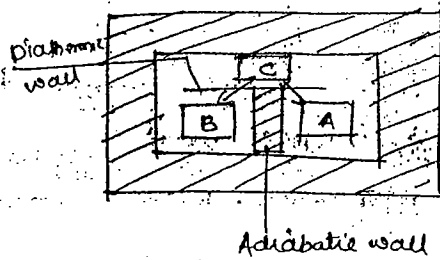
Hg is a Alcohol is

to pass

A series of process constitute a thermodynamics cycle. the minimum no. of process required are '2'

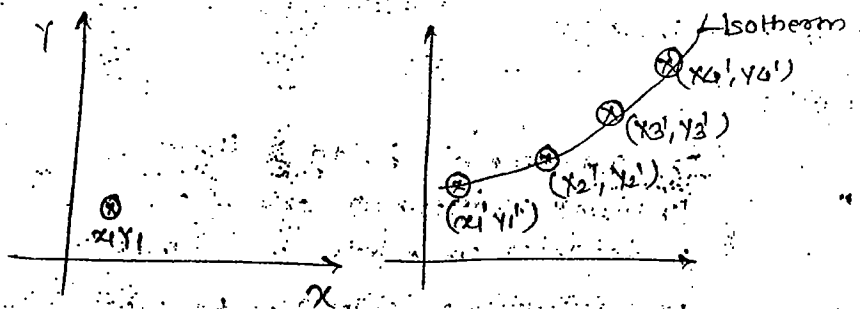


Zeroth's Law of thermodynamics



when two separate system are individually in thermal equilibrium with the third system then the two systems are in thermal equilibrium with one & another. which is called as zeroth law of thermodynamics.

Significance of Zeroth law is it gives us concept of temp and defines an isotherm



If we find a series of state on a system (which are in thermal equilibrium with one state of another system) then locus of all this state is called isotherm

The reference point for the measurement of temp is triple point of water. at that triple point of water we assumed that it is $(273.16\text{ K}, 0.01^\circ\text{C})$

The instrument used to measure the temp is called a thermometer. thermometer are of different type

① Liquid in glass thermometer

- Mercury thermometer
- Alcohol thermometer

Hg is used for high temp measurement

Alcohol is used for low temp measurement

② Gas thermometer

- constant volume type
- constant pressure type

In Cv type $p \propto T$ $\frac{p_1}{T_1} = \frac{p_2}{T_2}$

In p=c $V \propto T$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

③ Resistance thermometer

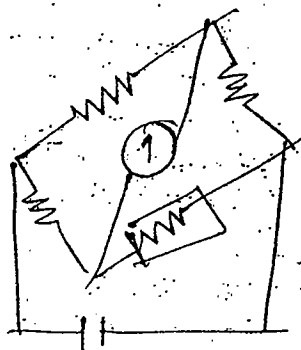
function on principle of change in resistance with temp as temp increases resistance increases. and here

$$R_t = R_0 (1 + At + Bt^2)$$

R_t = Resistance at temp t

R_0 = Resistance at temp 0°C

A, B = constants.



In wheatstone's bridges three known resistance and one resistance unknown resistance. unknown resistance is kept in place where temp measured.

$$R_t = R_0 (1 + At + Bt^2)$$

Thermocouple :

A thermocouple is formed by joining two dissimilar metal of thermal electrical series. one higher order element and another is lower order element. If the two junction are kepted at ice point and other at steam point. due to the difference in temp an emf is generated. and this emf is used to measure the temp.



Ice point

Magnet

It's fur
c. mag
highly
very low

pyromet
are used

Work of

Work
- No
- H

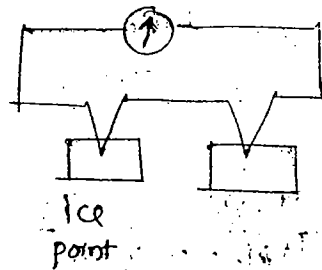
Non flow
- con

on a fixe
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basis be
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Non flow

$W_2 =$



$$emf = \epsilon = at + bt^2$$

$a, b = \text{constant}$
 $t = \text{temp}$

Magnetic thermometer

It's function on the principle adiabatic demagnetisation i.e. magnetisation & demagnetisation related to temp highly sensitive thermometer and used to measure very low temp of the order of -273°C .

Pyrometer: The function on principle of radiation they are used to measure temp from distance.

Work and Heat

Work

- Non flow work
- Flow work

Non flow work

- control mass

Flow work

- control volume

on a fixed mass of gas if some operation are performed it is called control mass and it is a non flow process and here mass is focus of attention

In a fixed control volume mass enters from one side and leaves from other side on a continuous basis here volume is focus of attention, hence it is control volume called flow process.

Non flow process (reversible)

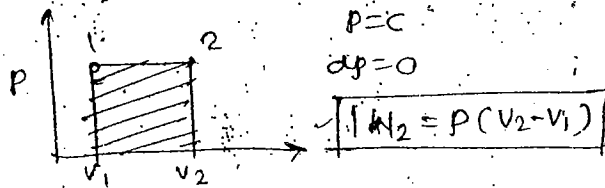
$$W_2 = \int_{v_1}^{v_2} p \, dv$$

$\uparrow$
 intensive property

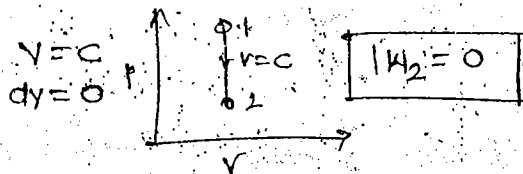
$\uparrow$
 change in extensive property

on pV diagram the area under curves gives the amount of heat & work done

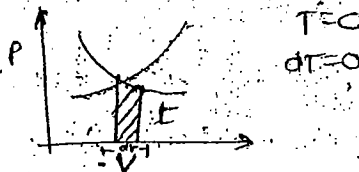
Isobaric process
Isopiestic process
constant pressure



Isochoric process
Isometric process
constant volume process



Isothermal process
constant temp process



Any process that is very slow is called constant temp process.

$$p_1 V_1 = p_2 V_2 = c$$

engine running at 1000 rpm, a tortoise walking, snail walking are examples of constant temp isothermal process.

$$W_2 = \int_{V_1}^{V_2} p dV = \int_{V_1}^{V_2} \frac{c}{V} dV = -c \ln \frac{V_2}{V_1}$$

$$= -c \cdot p_1 V_1 \ln \frac{V_2}{V_1} = -p_2 V_2 \ln \frac{V_2}{V_1}$$

$$= -m R T_1 \ln \frac{p_1}{p_2} = -m R T_2 \ln \frac{p_1}{p_2}$$

Adiabatic process:

It is superfast process i.e. very very fast process

burst in a balloon, burst in a car tyre, bursting of a bomb, engine running at 3000 rpm

$dQ = 0$ heat transfer is zero because there is no time to heat transfer takes place

$$p V^\gamma = c$$

$$T p^{\frac{\gamma-1}{\gamma}} = c$$

$$T p^{\frac{1}{\gamma}}$$

$$p V^\gamma = c$$

$$p_1 V_1^\gamma = p_2 V_2^\gamma$$

$$W_2 = \int_{V_1}^{V_2} p dV$$

$$= \frac{c}{-\gamma+1} \left[\frac{1}{V_2^{-\gamma+1}} - \frac{1}{V_1^{-\gamma+1}} \right]$$

polytropic

$$p V^n = c$$

$$T V^{n-1} = c$$

$$T p^{\frac{1-n}{n}} = c$$

$$W_2 = \int_{V_1}^{V_2} p dV$$

general all val

when n:

when r

work is

$$n=1$$

S-412

$$T P^{\frac{1-\gamma}{\gamma}} = C$$

$\gamma = \frac{C_p}{C_v}$ = ratio of specific heat

$\gamma = 1.4$ for air $\rightarrow$ diatomic gases, O_2, N_2

$\gamma = 1.6$ for monoatomic gases (helium, argon)

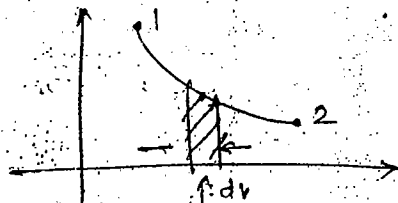
$\gamma = 1.33$ for triatomic gases (supersonic)

$$= P(V_2 - V_1)$$

$$u_2 = 0$$

$$P V^\gamma = C$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma = C$$



$$W_{12} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{C}{V^\gamma} dV = C \cdot \frac{V^{-\gamma+1}}{-\gamma+1} \Big|_{V_1}^{V_2}$$

$$= \frac{C}{-\gamma+1} [V_2^{-\gamma+1} - V_1^{-\gamma+1}]$$

$$= \frac{P_2 V_2^\gamma - P_1 V_1^\gamma}{-\gamma+1} = \frac{P_2 V_2^\gamma - P_1 V_1^\gamma}{-\gamma+1}$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{mR(T_1 - T_2)}{(\gamma - 1)}$$

$$= m C_v (T_1 - T_2)$$

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

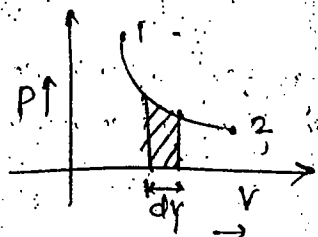
polytropic process

$$P V^n = C$$

n can take any value from 0 to ∞

$$T V^{n-1} = C$$

$$T P^{\frac{1-n}{n}} = C$$



$$W_{12} = \frac{P_1 V_1 - P_2 V_2}{n-1} = \frac{mR(T_1 - T_2)}{n-1}$$

general expression for workdone. this valid for all values of 'n' except $n=1$

when $n=1$ it is isothermal process

when $n=1$ polytropic work is infinite but isothermal work is finite hence it is not valid for

$$n=1$$

$$pv^n = c \quad \text{put } n=0 \quad p=c \quad \text{constant pressure process}$$

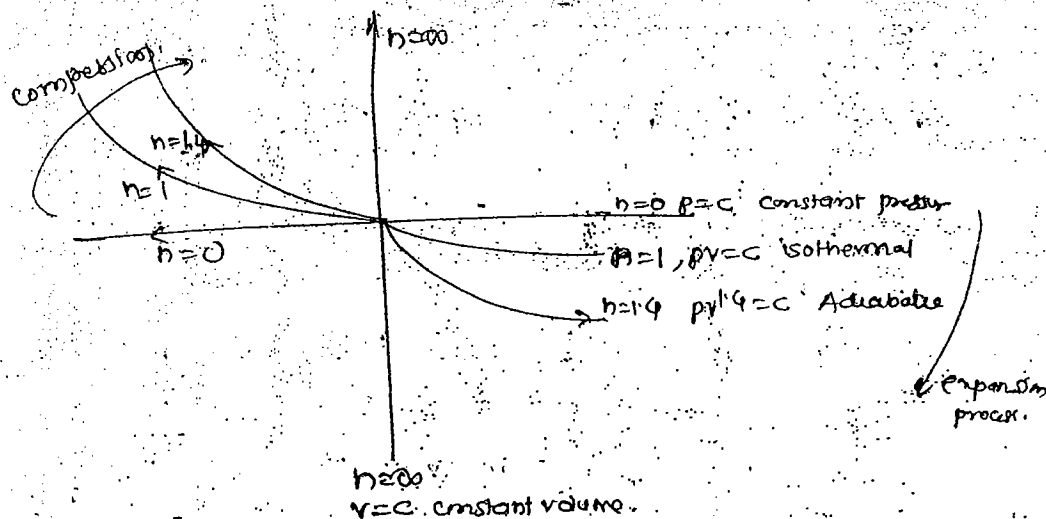
$$pv^n = c \quad \text{put } n=1 \quad pv=c \quad \text{isothermal}$$

$$pv^n = c \quad n=1.4 \quad pv^{1.4}=c \quad \text{Adiabatic process}$$

$$(pv^n)^{1/n} = c^{1/n} = c_1$$

$$p^{1/n} v = c_1$$

$$n=\infty \quad v=c \quad \text{constant volume process}$$



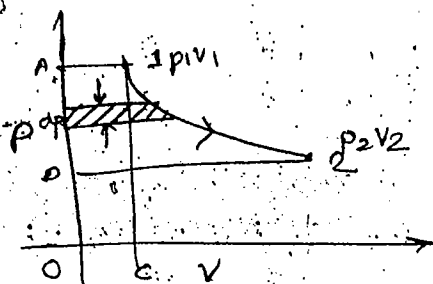
In expansion process as the value of n is increases from 0 to ∞ the work of expansion gas on decreasing

As value increasing for 0 to ∞ , in compression process the work of compression gas on increasing.

Flow work (irreversible)

$$W_2 = - \int_{v_1}^{v_2} v dp$$

Area to the left is workdone



$$\int v dp = \text{Area}_{OAC} + \text{Area}_{C2B} - \text{Area}_{O2B}$$

$$= p_1 v_1$$

$$\text{Isometric}$$

$$v=c$$

$$\int v dp =$$

$$\text{constant } p$$

$$p=c$$

$$dp=0$$

$$\text{isothermal}$$

$$T=c$$

$$dT=0$$

$$p_1 v_1 = p_2 v_2$$

$$\text{Adiabatic}$$

$$dq=$$

$$p_1 v_1 = p_2 v_2$$

$$= (1$$

$$= \frac{1}{\gamma}$$

$$= \frac{1}{\gamma}$$

$$= 1$$

$$\text{polytropic}$$

$$W_2 = C_1$$

isux process

$$= P_1 V_1 + \int P dv - P_2 V_2$$

this is when KE & PE are neglected.

case

Isometric or Isochoric

$$V = C, V_1 = V_2, dv = 0$$

$$\int v dp = P_1 V + 0 - P_2 V$$

$$= V(P_1 - P_2)$$

isochoric flow work is non-zero
where as isochoric non flow work is zero

constant pressure process

$$P = C, P_1 = P_2$$

$$dP = 0$$

$$W_2 = - \int v dp = 0$$

isobaric flow work is zero

isobaric non flow work is not zero.

Isothermal process

$$T = C$$

$$dT = 0$$

$$P_1 V_1 = P_2 V_2$$

$$\int v dp = P_1 V_1 + \int P dv - P_2 V_2$$

$$\int v dp = \int P dv = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= P_1 V_1 \ln \frac{P_1}{P_2}$$

$$= P_1 R T_1 \ln \frac{V_2}{V_1}$$

flow work & non flow work are same in isothermal process when KE & PE are neglected

constant pressure

Thermal

Adiabatic

expansion process

Adiabatic process

$$dq = 0$$

$$\int v dp = P_1 V_1 + \int P dv - P_2 V_2$$

$$= (P_1 V_1 - P_2 V_2) + \frac{(P_1 V_1 - P_2 V_2)}{\gamma - 1}$$

$$= \frac{\gamma}{\gamma - 1} (P_1 V_1 - P_2 V_2)$$

$$= \frac{\gamma}{\gamma - 1} R \cdot m (T_1 - T_2)$$

$$= m c_p (T_1 - T_2)$$

polytropic process

$$W_2 = (P_1 V_1 - P_2 V_2) \frac{n}{n - 1}$$

1/2

→

universal Gas equation

$PV = mRT$ — ① $P \Rightarrow$ pressure in N/m^2
 $V \Rightarrow$ vol^m in m^3
 $m \Rightarrow$ mass in kg
 $R \Rightarrow$ Gas constant $J/kg K$
 $T \Rightarrow$ Temp in K

$P = \frac{m}{V} RT$ $[P = \rho RT]$ — ② $\rho =$ density in kg/m^3
 $P \frac{V}{m} = RT$ $[PV = RT]$ — ③ $V =$ specific volume m^3/kg

$R = \frac{\bar{R}}{M}$ $\bar{R} =$ universal gas constant $\bar{R} = 8.314 J/kg mole K$
 $M =$ Molecular weight of gas $= 8314 J/kg mole K$

$PV = mRT$ $PV = m \frac{\bar{R}}{M} T$ $[PV = \frac{m}{M} \bar{R} T]$

$n = \text{no. of moles} = \frac{m}{M}$ $n = \text{no. of mol}$
 $= \frac{\text{no. of molecule}}{\text{Avogadro number}} = \frac{N}{A}$

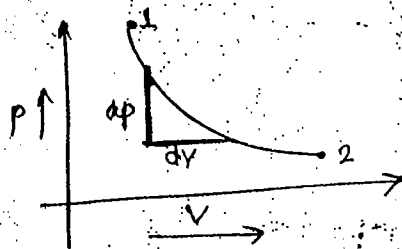
$PV = nRT = \frac{N}{A} RT = N \frac{\bar{R}}{A} T = NkT$

$k = \frac{\bar{R}}{A}$ $\bar{R} =$ universal gas constant
 $A =$ Avogadro No.

$k = \frac{8.314}{6.023 \times 10^{23}} = 1.38 \times 10^{-23}$

what is the slope of an isothermal curve on PV plane

$PV = C$
 $PdV + VdP = 0$
 $\left(\frac{dP}{dV}\right)_{T=C} = -\frac{P}{V}$

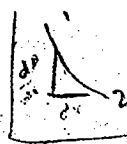


* what is slope of adiabatic curve on PV plane

slope of adiabatic > slope of isothermal

$PV^\gamma = C$
 $d(PV^\gamma) + P \cdot \gamma V^{\gamma-1} dV = 0$

$\left(\frac{dP}{dV}\right)_{T=C} = -\frac{\gamma P}{V} = -\gamma \left(\frac{dP}{dV}\right)_{T=C}$



* what is the

$TV^{\gamma-1} = C$

$\left(\frac{dT}{dV}\right)_{S=C}$

* what is the

$TP^{\frac{\gamma-1}{\gamma}} = C$

$\left(\frac{dT}{dP}\right)_{S=C}$

* what is the

$PV = C$

$n = -1$

* what is the

$\log P \text{ vs } \log V$

$\Rightarrow PV^\gamma = C$

* what is the

$TV^{\gamma-1} = C$

* what is the

$TP^{\frac{1-\gamma}{\gamma}} = C$

$\therefore \ln T =$

$y =$

* what is the slope of an adiabatic curve on T - V plane

$$TV^{\gamma-1} = C, \quad d(TV^{\gamma-1}) + T(\gamma-1)V^{\gamma-2}dV = 0$$

$$\left(\frac{dT}{dV}\right)_{S=C} = (1-\gamma) \frac{T}{V}$$

* what is the slope of adiabatic curve on T - P plane

$$TP^{\frac{\gamma-1}{\gamma}} = C, \quad d(TP^{\frac{\gamma-1}{\gamma}}) + T\left(\frac{\gamma-1}{\gamma}\right)P^{\frac{\gamma-1}{\gamma}-1}dP = 0$$

$$\left(\frac{dT}{dP}\right)_{S=C} = \left(\frac{\gamma-1}{\gamma}\right) \frac{T}{P}$$

* what is the slope of an isothermal curve on $\log P$ vs $\log V$ plane

$$PV = C, \quad \ln P + \ln V = \ln C, \quad \ln P = \ln C - \ln V, \quad y = c + mx$$

$$\boxed{m = -1}$$

* what is the slope of an adiabatic curve on P - V plane
 $\log P$ vs $\log V$ plane

$$PV^{\gamma} = C, \quad \ln P + \gamma \ln V = \ln C, \quad \ln P = \ln C - \gamma \ln V$$

$$\boxed{m = -\gamma}$$

* what is the slope of an adiabatic curve on $\log T$ vs $\log V$ plane

$$TV^{\gamma-1} = C, \quad \ln T + (\gamma-1) \ln V = \ln C, \quad \ln T = \ln C - (\gamma-1) \ln V$$

$$y = c + mx$$

$$\boxed{m = 1-\gamma}$$

* what is the slope of an adiabatic curve on $\ln T$ vs $\ln P$ plane

$$TP^{\frac{\gamma-1}{\gamma}} = C, \quad \ln T + \left(\frac{\gamma-1}{\gamma}\right) \ln P = \ln C$$

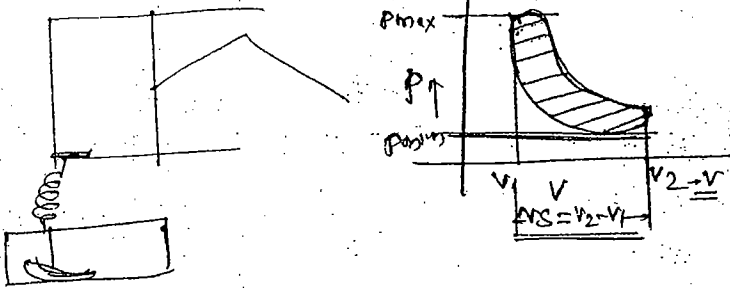
$$\ln T = \ln C - \frac{\gamma-1}{\gamma} \ln P$$

$$y = c + mx, \quad m = -\frac{\gamma-1}{\gamma}$$

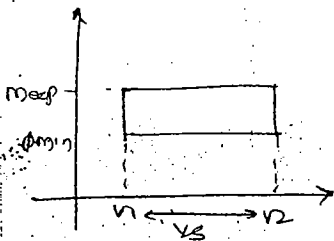
slope of isothermal

Indicator diagram

It is an instrument used for measuring the work done by I.C engine. The pressure and volume changes taking place inside the engine cylinder are sensed by a sensor which are transmitted to a Reed wright mechanism via spring loaded device and block of p-v diagram is obtained and area of p-v diagram represent workdone.



If the area of indicated diagram is uniformly distributed along the x-axis the average obtained is called as mean effective pressure (m.e.p)



m.e.p is indication of the amount of workdone by I.C engine.

Indicated power

$$(I.P.) (kW) = \frac{P_{mi} L A N \cdot h}{120,000}$$

120,000 = 4 stroke

60,000 = 2 stroke

$P_{mi} = (m.e.p) \text{ in Pascal}$

$L = \text{stroke length in m}$

$A = \text{c/s area in } m^2$

$N = \text{rpm}$

$h = \text{no. of cylinder}$

m.e.p is obtained from the indicated diagram

$$m.e.p = \frac{\text{Area of indicator diagram}}{\text{length of indicator diagram}} \times \text{spring constant}$$

$$= \frac{m^2}{m} \times K \quad K = \text{MPa/m, kPa/m, Bar/cm, kN/m}^2/\text{m}$$

K is having pressure unit divided by length unit

$$m.e.p = \frac{A_d}{L_d} \times K$$

First Law

$$\oint \delta Q$$

In a cycle
Sum of work

$$\oint \delta Q - \oint \delta W$$

Internal energy due to the motion or vibration of rotational having translational above energy

$$Q - W = \Delta U$$

$$dQ - dW = dU$$

an exact differential does not depend on path

Specific heat

The rate of change of temperature at

Enthalpy

It is a thermodynamic property

$$C_p = \left(\frac{\partial h}{\partial T} \right)_p$$

It is defined in terms of temperature

$$C_p = \left(\frac{\partial h}{\partial T} \right)_p$$

Mc

work done by
towing
sensor
m. via
is obtained

First Law of Thermodynamics:

$$\oint \delta q = \oint \delta w$$

In a cyclic process the sum of the heat interaction is equal
Sum of work interaction

$$\oint \delta q - \oint \delta w = 0$$

$$q - w = K \quad K \Rightarrow \text{constant of integration}$$

Internal energy basically due to the molecular motion or intermolecular forces. molecule as in state of vibration there having molecular state of rotation having rotational energy molecule in state of translation they are having translational energy and electron energy the sum of all the above energy is called as internal energy of the system.

$$K \Rightarrow I \cdot E + P \cdot E + K \cdot E$$

Microscopic
Microscopic
Microscopic

motion or intermolecular forces. molecule as in state of vibration there having molecular state of rotation having rotational energy molecule in state of translation they are having translational energy and electron energy the sum of all the above energy is called as internal energy of the system.

rotational energy molecule in state of translation they are having translational energy and electron energy the sum of all the above energy is called as internal energy of the system.

y distributed
has been

$$q - w = U$$

$$\boxed{\delta q - \delta w = dU}$$

heat and work are path function

Internal energy is point function which is an exact differential it depends only on end state but does not depend upon the path followed.

re amount

Specific heat at cv

The ratio of change in internal energy to the change in temp at constant volume

Enthalpy:

It is defined as $h = U + PV$

PV = flow work

U = Internal energy

$$C_p = \left(\frac{\partial h}{\partial T} \right)_{P=C} \quad \text{Specific heat at } C_p$$

It is defined as ratio of change in enthalpy to the change in temp at constant pressure

$$C_p = \left(\frac{\partial h}{\partial T} \right)_{P=C}$$

$$C_p - C_v = R$$

$$R = \frac{\bar{R}}{M}$$

$$M C_p - M C_v = \bar{R}$$

unit

∴ difference betⁿ the molar specific heat at constant pressure and the molar specific heat at constant volume is equal to universal gas constant R .

$$C_p - C_v = R \quad \gamma = \frac{C_p}{C_v} \text{ which is called as ratio of Specific heat}$$

$$\gamma = 1.67 \text{ — monoatomic gas}$$

$$\gamma = 1.4 \text{ — diatomic gases}$$

$$\gamma = 1.33 \text{ — polyatomic gases}$$

$$C_v (\gamma - 1) = R \quad C_v = \frac{R}{\gamma - 1}$$

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

Monoatomic molecule having three translational motion therefore degree of freedom are 3.

diatomic molecule are having 5 degree of freedom

3 translational motion and 2 rotational motions and D.O.F are 5.

polyatomic molecules are having 6 or 7 D.O.F. either 2 D.O.F or 3 D.O.F are omitted based on the type of bonding.

$$\boxed{\text{Internal energy} = \frac{\alpha}{2} RT} \quad \alpha = \text{degree of freedom}$$

$$C_v = \frac{dU}{dT} = \frac{\alpha}{2} R = R$$

$$\text{enthalpy } h = U + pV = \frac{\alpha}{2} RT + RT = \left(\frac{\alpha}{2} + 1 \right) RT$$

$$C_p = \left(\frac{\partial h}{\partial T} \right)_{p=c} = \left(\frac{\alpha}{2} + 1 \right) R$$

$$\gamma = \frac{C_p}{C_v} = \frac{\left(\frac{\alpha}{2} + 1 \right) R}{1 + \frac{\alpha}{2}}$$

$$\alpha = 3 \text{ for monoatomic gases} \quad \gamma = 5/3$$

$$\alpha = 5 \text{ for diatomic gases} \quad \gamma = 7/5$$

$$\alpha = 6 \text{ or } 7 \text{ for polyatomic gases} \quad \gamma = 4/3$$

C_p, C_v and γ

for real g values incre where as γ with temp.

$$dq + dw = 0$$

Isochoric pr

In a cons m internal e

Isothermal

In isothermal

Adiabatic

$$dT = - \frac{dw}{C_v}$$

Expansio

dw (+ve)

dT (-ve)

$$dT_f - T_i < 0$$

$$T_f < T_i$$

Adiabatic exp cooling effect

a puncture of valve of bicy

Now let u

$$dq + dw = 0$$

$$dq = -dw$$

$$du = dq + dw$$

$$du = 0$$

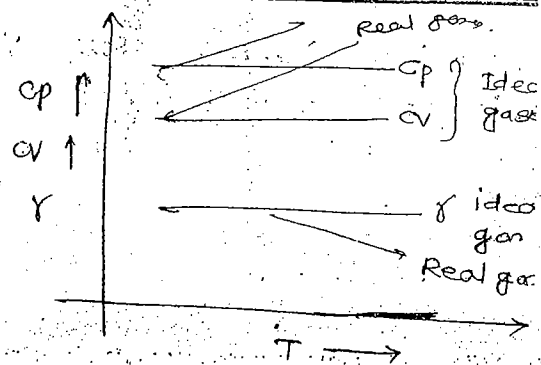
$$u = \text{const}$$

$$\boxed{u = \text{const}}$$

constant pressure
equal to

C_p , C_v and γ values

for real gas C_p and C_v
values increase with temp.
whereas γ values decrease
with temp.



Specific heat

$$dq - dw = du$$

Isochoric process $\therefore V = C, dV = 0$

$$\therefore dw = 0, dq = du$$

In a constant vol^m process heat transfer equal to change
in internal energy of the system.

Isothermal process $T = C, dT = 0, du = 0$ $dq = dw$

In isothermal process heat transfer equal to work transfer

Adiabatic process $dq = 0, du = -dw$ $C_v dT = -dw$

$$dT = -\frac{dw}{C_v}$$

Expansion

$dw (+ve)$

$dT (-ve)$

$$dT_f - T_i < 0$$

$$T_f < T_i$$

Adiabatic expansion produces
a cooling effect

$\therefore$ puncture of football, remove
valve of bicycle (cooling effect produced)

Compression

$dw (-ve)$

$dT (+ve)$

$$T_f - T_i > 0$$

$$T_f > T_i$$

Adiabatic compression produces
heating effect.

Now let us apply 1st law to isolated system.

$$dq - dw = du$$

$$dq = 0$$

$$dw = 0$$

$$\therefore du = 0$$

$$u = C$$

$$\boxed{u_2 = u_1}$$

for isolated system the internal
energy remain constant

on a hot summer day the room is perfectly insulated and refrigerator door is kept open and will happen to temp of room. refrigerator is connected to external mean.

$$\Rightarrow dq - dw = du$$

$$0 - dw = cv dt$$

Expansion

$$dT = -\frac{dw}{cv}$$

$$= -\left(-\frac{dw}{cv}\right)$$

compression

$$\sum \frac{dw}{cv} > 0$$

$$T_f - T_i > 0$$

$$T_f > T_i$$

Across the terminal of battery a resistor is connected and if resistance is considered as a system what are the heat work & energy interaction.

$$Q = 0, \quad W = -ve, \quad U = +ve$$

(heat process) (Adiabatic)

If considered battery as the system

$$Q = 0, \quad W = +ve, \quad U = -ve$$

A battery is kept in open circuit for a long time what are the signs of heat, work and energy interaction. if battery is considered as the system

$$Q = -ve, \quad W = 0, \quad U = -ve$$

1st Law is quantitative law. It is directionless. It says that energy in one form is converted to energy in another form, but does not specify the direction.

$$\dot{Q} = \dot{W}$$

PMM 1st Law

The corner



Steady

$$\dot{m} = \rho A V$$

Pressure p , kPa

Specific volume v , $\frac{m^3}{kg}$

Enthalpy h , $\frac{kJ}{kg}$

velocity V , $\frac{m}{s}$

elevation z , m

Mass flow rate $\dot{m}$

Area A

For Steady

Condition

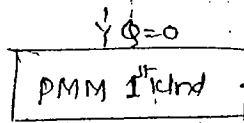
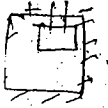
① Mass

$$\dot{m}_1 = \dot{m}_2$$

$$\sum A_i V_i = 0$$

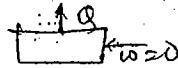
$$\frac{A_i V_i}{V_i} = 0$$

ctly
and will
led to

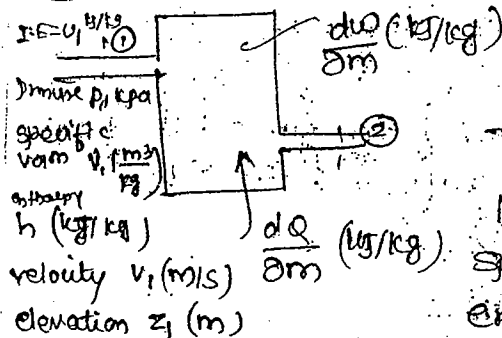


without energy input getting some output
is called perpetual motion of 1st type.
and PMM of 1st kind is impossible

The converse of the statement is also true with any some
input, getting heat input is also impossible.



Steady flow Energy equation (SFEE)



Mass flow = $\dot{m}$ (kg/sec)
rate
C/s Area = $A_1 = A_2$ (m²)

at section 2

$$I.E = U_2 = \text{kJ/kg}$$

$$\text{pressure } p_2 = \text{kPa}$$

$$\text{sp. volume} = v_2 = (\text{m}^3/\text{kg})$$

$$\text{enthalpy} = h_2 = (\text{kJ/kg})$$

$$\text{velocity } v_2 = (\text{m/s})$$

$$\text{Elevation} \rightarrow z_2 (\text{kg/sec})$$

$$\text{C/s Area} \rightarrow A_2 (\text{m}^2)$$

For steady flow condition to prevail two
condition are to be satisfied

① Mass balance

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$\frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2}$$

② Energy balance

$$* K.E = \frac{1}{2} m v^2$$

$$\frac{K.E}{m} = \frac{v^2}{2} (\text{J/kg})$$

$$\frac{K.E}{m} = \frac{v^2}{2000} (\text{kJ/kg})$$

$$* P.E = m g z (\text{J})$$

$$\frac{P.E}{m} = g z (\text{J/kg})$$

$$\frac{P.E}{m} = \frac{g z}{1000} (\text{kJ/kg})$$

Energy balance

$$I.E + P.E + K.E + P.E + \text{Heat energy}$$

$$= I.E + P.E + K.E + P.E + \text{Work energy}$$

Energy balance

$$U_1 + p_1 v_1 + \frac{v_1^2}{2000} + \frac{z_1 g}{1000} + \frac{dq}{dm} = U_2 + p_2 v_2 + \frac{v_2^2}{2000} + \frac{z_2 g}{1000} + \frac{dw}{dm}$$

$$h_1 + \frac{v_1^2}{2000} + \frac{z_1 g}{1000} + \frac{dq}{dm} = h_2 + \frac{v_2^2}{2000} + \frac{z_2 g}{1000} + \frac{dw}{dm}$$

$$\boxed{h_1 + \frac{dq}{dm} = h_2 + \frac{dw}{dm}} \quad \text{SFEE on mass basis}$$

— mass basis $KE = PE = 0$

mass based eqn can be converted to time based eqn by multiplying with mass flow rate on both side

$$\dot{m} \left[h_1 + \frac{v_1^2}{2000} + \frac{z_1 g}{1000} \right] + \frac{dq}{dm} \times \frac{dm}{dt} = \dot{m} \left[h_2 + \frac{v_2^2}{2000} + \frac{z_2 g}{1000} \right] + \frac{dw}{dm} \times \frac{dm}{dt}$$

$$\boxed{\dot{m} \left[h_1 + \frac{v_1^2}{2000} + \frac{z_1 g}{1000} \right] + \frac{dq}{dt} = \dot{m} \left[h_2 + \frac{v_2^2}{2000} + \frac{z_2 g}{1000} \right] + \frac{dw}{dt}}$$

SFEE on time basis

if $KE, PE = 0$

$$\boxed{\dot{m} h_1 + \frac{dq}{dt} = \dot{m} h_2 + \frac{dw}{dt}}$$

SFEE is Bernoulli's eqn is special case of SFEE

SFEE is for compressible fluids

Bernoulli's eqn is for incompressible fluids

hence it's special case

Applications

① Nozzle energy to

h_1 kJ/kg

v_1 m/sec

insula

Apply SFEE

$v_1 = 0$

The enthalpy

② Turbine converting

h_1 (kJ/kg)

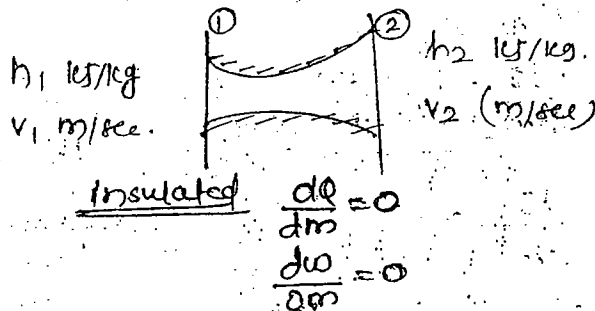
$\frac{dq}{dm} =$

$h_1 +$

work done by the

Applications of SFEE

① Nozzle: A nozzle is a device which convert heat energy to KE



Apply SFEE

$$h_1 + \frac{v_1^2}{2000} + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2000} + \frac{dW}{dm}$$

$$v_2 = \sqrt{v_1^2 + 2000(h_1 - h_2)}$$

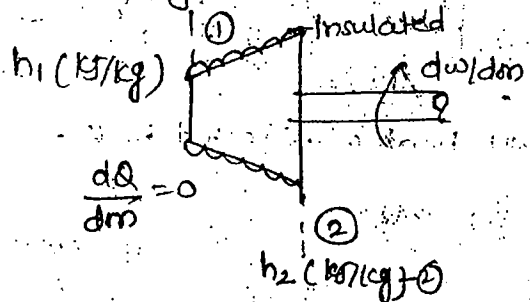
$$v_1 = 0$$

$$v_2 = 44.72 \sqrt{\Delta h}$$

$$\Delta h = \text{kJ/kg}$$

The enthalpy drop is converted into K.E

② Turbine: Turbine is device which is used for converting heat energy to work energy



$$h_1 + \frac{dQ}{dm} = h_2 + \frac{dW}{dm}$$

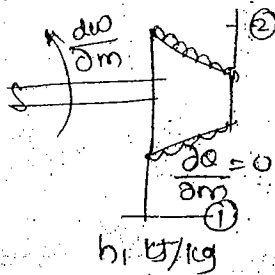
$$\frac{dW}{dm} = h_1 - h_2 \text{ kJ/kg}$$

Work is 'in' and work is said to be done by the system.

In turbine high pressure fluid expand and in process does work.

Compressor

It is device which convert low pressure fluid to a high pressure fluid by doing external work.



$$h_1 + \frac{dQ}{dm} = h_2 + \frac{dw}{dm}$$

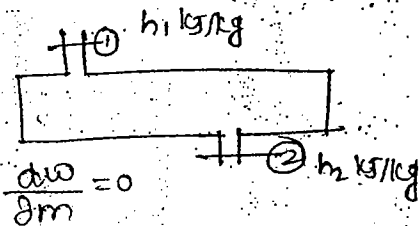
$$\frac{dQ}{dm} = 0$$

$$\boxed{\frac{dw}{dm} = h_2 - h_1} \text{ kJ/kg}$$

The ans is +ve indicating that the external agent is doing work on the system.

Condensor

It is device which is used for rejecting heat



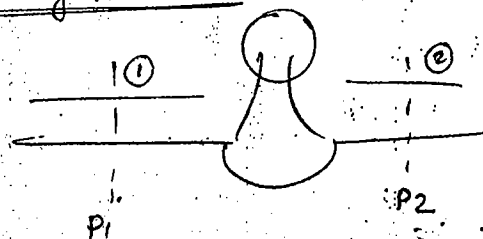
$$h_1 + \frac{dQ}{dm} = h_2 + \frac{dw}{dm}$$

$$\boxed{\frac{dQ}{dm} = h_2 - h_1} \text{ kJ/kg}$$

Ans -ve

Answer is -ve indicating that heat is rejected by the system.

Throttling process



$$\frac{dQ}{dm} = 0 \quad \frac{dw}{dm} = 0$$

$$P_2 ; P_1 > P_2$$

$$h_1 + \frac{dQ}{dm} =$$

$$h_1 = h_2$$

$$cp(T_1 - 0) =$$

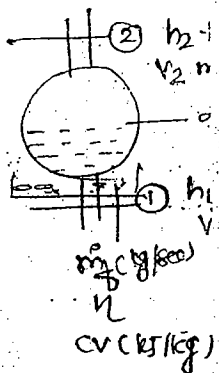
$$T_1 = T_2$$

$$\therefore P_1 V_1 < P_2$$

For steam

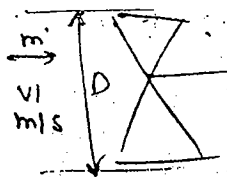
It is also

Boiler



$$m_f =$$

Wind mill



power prod
dia or

It does work.

fluid to a

$$h_1 + \frac{dQ}{dm} = h_2 + \frac{dW}{dm}$$

$$h_1 = h_2$$

$$C_p(T_1 - 0) = C_p(T_2 - 0)$$

$T_1 = T_2 \rightarrow$ Ideal gas

For ideal gases in a throttling process temp remain constant.

$$U_1 + P_1 V_1 = U_2 + P_2 V_2$$

$$U_2 = U_1 + P_1 V_1 - P_2 V_2$$

$$P_1 V_1 > P_2 V_2$$

$$\therefore V_2 > V_1 + x \quad \therefore T_2 > T_1$$

$$\therefore P_1 V_1 < P_2 V_2$$

$$V_2 = V_1 + x$$

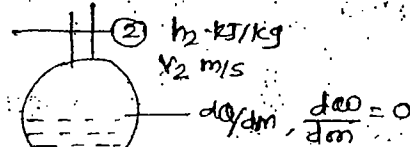
$$T_2 < T_1$$

$\rightarrow$ This is for Real gas

For steam due to throttling temperature decreases. Throttling process is also called wire drawing process.

Boiler: It is a device which is used for raising steam.

agent is



$$h_1 + \frac{v_1^2}{2000} + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2000} + \frac{dW}{dm}$$

$$\frac{dQ}{dm} = (h_2 - h_1) + \frac{v_2^2 - v_1^2}{2000} \quad \text{kJ/kg}$$

heat

$$\frac{m_f (\text{kg/sec})}{CV (\text{kJ/kg})} \times \eta_c$$

Let m_s kg/s be the amount of steam generated. This is m_s .

Heat supplied by fuel = Heat required to raise the st

$$m_f \left(\frac{\text{kg}}{\text{sec}} \right) \times CV (\text{kJ/kg}) \times \eta_c = m_s (\text{kg/sec}) \times \frac{dQ}{dm} (\text{kJ/kg})$$

$$m_f = \frac{m_s \times \frac{dQ}{dm}}{CV \times \eta_c}$$

id by the

Wind mill:

$$\text{power (watt)} = \frac{1}{2} m (v_1^2 - v_2^2)$$

$$= \frac{1}{2} m v^2$$

m = mass flow rate of air = $\rho a v$

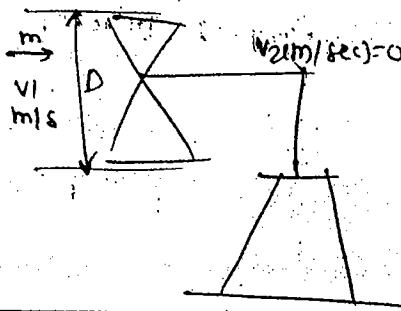
$$= \frac{1}{2} \rho a v^3 = \frac{1}{2} \rho a v^3$$

$$= \frac{1}{2} \rho \frac{\pi}{4} D^2 v^3$$

$$P(w) = \frac{\pi \rho}{8} D^2 v^3$$

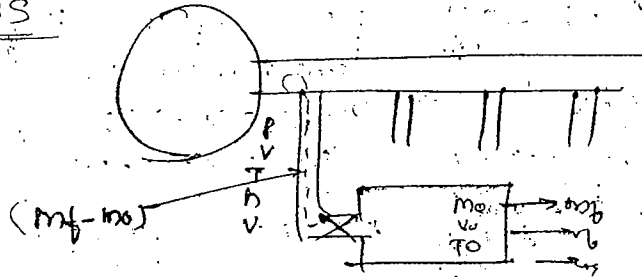
$$P \propto D^2 v^3$$

power produce in windmill is directly proportional square of dia and cube of velocity



Charging process

$$W = -P(m_f - m_0)V$$



$$\text{Initial energy} = E_1 = m_0 v_0 + (m_f - m_0) u$$

$$\text{Final energy} = E_2 = m_f v_f$$

$$Q - W = E_2 - E_1$$

$$Q + P(m_f - m_0)V = m_f v_f - (m_0 v_0 + (m_f - m_0)u)$$

$$Q = m_f v_f - m_0 v_0 - (m_f - m_0)u - P(m_f - m_0)V$$

$$= m_f v_f - m_0 v_0 - (m_f - m_0)(u + Pv)$$

$$Q = m_f v_f - m_0 v_0 - (m_f - m_0)h \quad \text{--- (1)}$$

Let us assume Adiabatic process

Adiabatic $Q = 0, m_0 = 0$

There is no mass of gas in the cylinder

$$0 = m_f v_f - m_f h$$

$$h = v_f$$

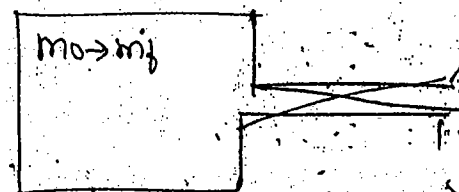
$$C_p T = C_v T_f$$

$$T_f = \frac{C_p}{C_v} T$$

$$T_f = \gamma T \quad \text{--- is called as Charging process}$$

Discharging process

The opposite to charging process is discharging process.



$$(m_0 - m_f)$$

$$V$$

Initially in
and temp

Amount

Initial

fluid en

W

E_2

$Q =$

$Q =$

$Q =$

let imp

① Adia

$\Rightarrow$

Q

h

$C_p T$

$T_0 =$

*

Pg. No 2

Ch. No 10

$F_{net} = P_a$

$= 500$

$= P_a$

$= 500$

$= 3$

Initially in the cylinder the mass is m^0 and internal energy U^0 and temp is T^0 it become $m^0 v^0, T^0$

Amount of mass come out the system is $m^0 - m$

Initial Energy = $E_1 = m^0 v^0$

fluid energy = $E_2 = m_f v_f + (m^0 - m_f) v$

$W = (m^0 - m_f) p v$

$E_2 - E_1$

$Q - (m^0 - m_f) p v = m_f v_f + (m^0 - m_f) v - m^0 v^0$

$Q = m_f v_f \cdot m^0 v^0 + (m^0 - m_f) v + (m^0 - m_f) p v$

$Q = m_f v_f \cdot m^0 v^0 + (m^0 - m_f) h$

let impose on

① Adiabatic ② find final mass of gas inside the cylinder

$0 = -m^0 v^0 + m h$

$h = v^0$

$C_p(T - T^0) = C_v(T^0 - T^0)$

$T^0 = \frac{C_p}{C_v} T = \gamma T = \gamma_1$

$p^0 = \frac{\gamma}{\gamma - 1} \rho \cdot v^0$

*

pg. No 2.

Qu. No 10:

$F_{net} = P_A A_A - P_0 (A_A - A_B)$

$= \frac{m p g}{1000}$

$= 800$

$= P_A \times \frac{\pi}{4} D_A^2 - P_0 \times \frac{\pi}{4} (D_A^2 - D_B^2)$

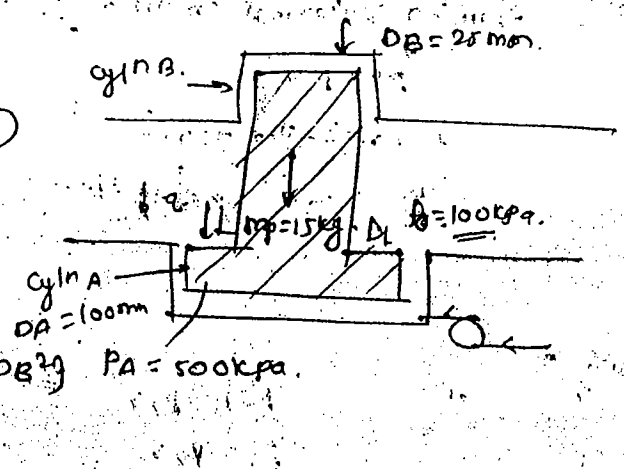
$= \frac{m p g}{1000}$

$= 500 \times 0.2854 \times 10 \times 10^3 + 100 \times 0.2854 (10 \times 10^3 - 625) - \frac{5 \times 9.81}{1000}$

$= 3927 \times 10^3 - 736.3125 \times 10^3 - 0.14715$

$= 3.1906 \times 10^6 \text{ N.} = 3.092 \text{ kN.}$

problems on 1st law and work sheet



$$P_B = \frac{F_{net}}{A_B} = \frac{3.042}{\frac{\pi}{4} \times D_B^2} = \frac{3.042}{\frac{\pi}{4} \times (0.025)^2} = 6197.09 = 6.2 \text{ MPa}$$

Q4.7 $P_1 = P_2$
 $d_1 = 20$

$P_2 = P_{atm}$

Q4.2 $P_{abs} = P_{atm} + P_g = 1.023 + 25 = 26.03 \text{ bar}$

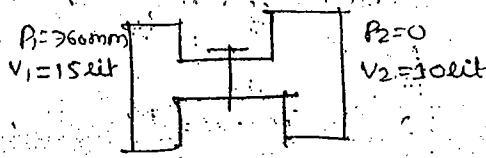
$P_1 V_1 = P_2 V_2$

$57 \times 20 = 95$

$d_2 = \frac{57 \times 2}{95}$

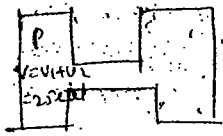
$d_2 = 1.2 \text{ cm}$

Q4.3 $P_1 V_1 + P_2 V_2 = P V$
 $760 \times 15 + 0 \times 10 = P \times 25$



$P = \frac{760 \times 15}{25}$

$P = 456 \text{ mm of Hg}$

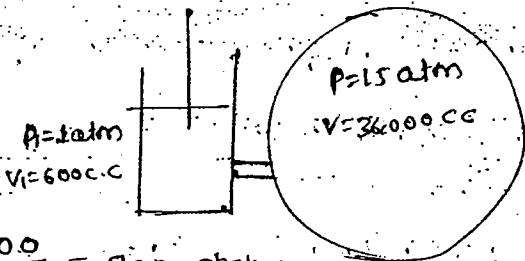


Q4.4

$n = \text{no. of stroke}$
Assuming condition

$n P_1 V_1 = P V$

$n = \frac{P V}{P_1 V_1} = \frac{1.5 \times 36000}{1 \times 600} = 900 \text{ strokes}$



Q4.11

$P V^{1.4} = 2.25$

$= 2.25$

$V^{1.4} = \left(\frac{2}{V}\right)$

$V = 66$

$ap = \frac{3}{8}$

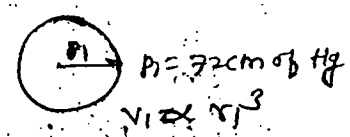
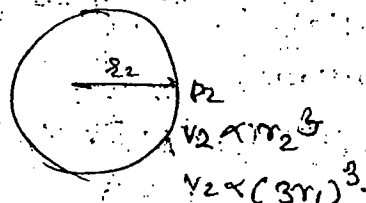
$dh =$

Q4.5 Assuming isothermal condition

$P_1 V_1 = P_2 V_2$

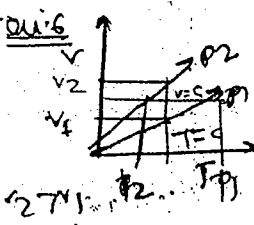
$72 \times (r_1)^3 = P_2 \times 27 \times r_1^3$

$P_2 = 2.67 \text{ cm of Hg}$



$dh =$

$\int_0^h dh =$



$P_1 V_1 = P_2 V_2$

$P_1 = \frac{P_2 V_2}{V_1}$

$P_1 > P_2$

$T_1 > T_2$

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$

$P_1 = P_2 \times \frac{T_1}{T_2}$

$P_1 > P_2$

$$= 6.2 \text{ MPa}$$

$$\text{Ans: } P_1 = P_{\text{atm}} - 19 = 76 - 19 = 57$$

$$l_1 = 20 \text{ cm}$$

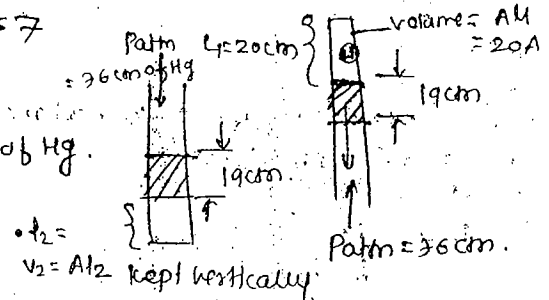
$$P_2 = P_{\text{atm}} + 19 = 76 + 19 = 95 \text{ cm of Hg}$$

$$P_1 V_1 = P_2 V_2$$

$$57 \times 20A = 95 \times A l_2$$

$$l_2 = \frac{57 \times 20A}{95A}$$

$$l_2 = 12 \text{ cm}$$



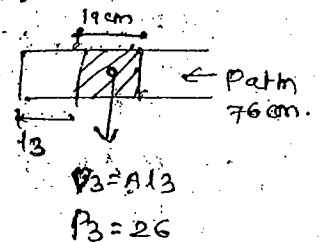
P2 =

if capillary tube is kept horizontal what is the length of air craft

$$P_1 V_1 = P_2 V_2 = P_3 V_3$$

$$57 \times 20A = 26 \times A l_3$$

$$l_3 = 15 \text{ cm}$$



Ques 11

$$P V^{1.4} = 2.256 \text{ bar} \left(\frac{\text{m}^3}{\text{kg}} \right)$$

$$= 2.256 \times 10^5 \left(\frac{\text{m}^3}{\text{kg}} \right)$$

$$V^{1.4} = \left(\frac{2.256 \times 10^5}{P} \right)^{1/1.4}$$

$$V = 6665.2 P^{-1/1.4}$$

$$dp = \frac{\rho g dh}{\rho c}$$

$$dh = \frac{\rho c}{\rho g} dp$$

$$= \frac{\rho c}{g} V dp$$

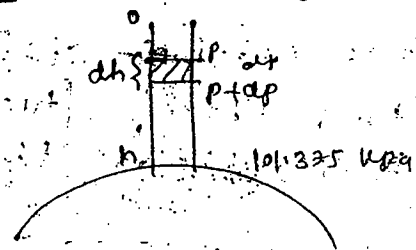
$$dh = \frac{1}{9.81} \times 6665.2 P^{-1/1.4} dp$$

$$\int_0^h dh = \frac{1}{9.81} \times 6665.2 \int_{101325}^{101325} P^{-1/1.4} dp$$

$$= 679.42 \left[\frac{P^{-1/1.4}}{-1/1.4} + 1 \right]_{101325}^{101325}$$

$$= 679.42 \left[\frac{101325^{-1/1.4}}{-1/1.4} + 1 \right] = 64034.071 \text{ m}$$

$$= 64.034 \text{ km}$$



Q1.13

When centripetal force is balanced by gravitational force -

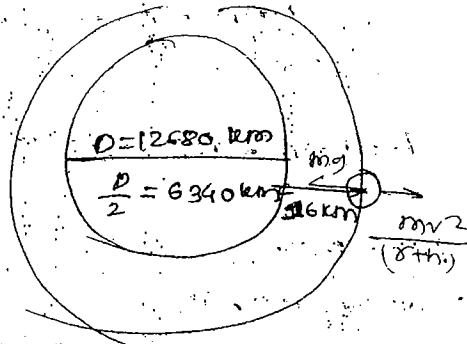
$$mg = \frac{mv^2}{(R+h)}$$

$$g = \frac{v^2}{R+h}$$

$$= \frac{(28,840 \times \frac{5}{18})^2}{(6340 + 816) \times 10^3}$$

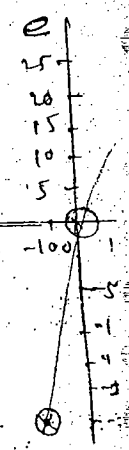
$$g = 8.89$$

$$W = \frac{mg}{g_c} = \frac{86 \times 8.89}{1} = 760.65 \text{ N}$$



Q1.14

t1 =
t2 =
t3 =
Q10 = t4 =
t5 =



Q1.14

$$t_a = a + b t_b + c t_b^2$$

$$t_a = 0 \quad t_b = 0$$

$$t_a = 51 \quad t_b = 50$$

$$t_a = 100 \quad t_b = 100$$

$$0 = a + 0 + 0$$

$$a = 0$$

$$100 = 100b + 10^4 c$$

$$51 = 50b + 2500c$$

$$b = 1.04$$

$$c = -4 \times 10^{-4}$$

$$t_a = 1.04 t_b - 4 \times 10^{-4} t_b^2$$

$$t_b = 26$$

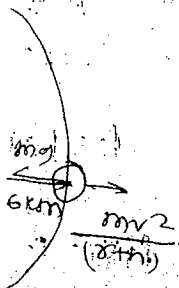
$$t_a = 1.04 \times 26 - 4 \times 10^{-4} (26)^2$$

$$t_a = 26.76^\circ \text{C}$$

Q1.16

unless construction feature of thermometers are known and the condition under which is known it is not possible to comment

It



Ques 15 $e = at + bt^2$

$$= 0.2t - 5 \times 10^{-4} t^2$$

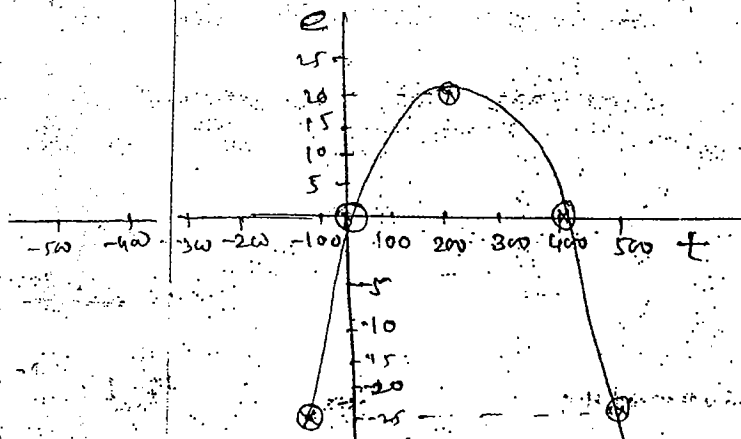
$$t_1 = -100^\circ\text{C} \quad e_1 = (0.2)(-100) - 5 \times 10^{-4} (-100)^2 = -25 \text{ mV}$$

$$t_2 = 0 \quad e_2 = 0$$

$$t_3 = (0.2)(200) - 5 \times 10^{-4} (200)^2 = 20 \text{ mV}$$

$$400 = t_4 = 0.2(400) - 5 \times 10^{-4} (400)^2 = 0$$

$$t_5 = 500^\circ\text{C} = 0.2(500) - 5 \times 10^{-4} (500)^2 = -25 \text{ mV}$$



Ques 16 $t = a \ln k + b$

$$t = 0 \quad t = 100$$

$$k = 1.83 \quad k = 6.78$$

$$0 = a \ln 1.83 + b, \quad 100 = a \ln 6.78 + b$$

$$\boxed{a = 76.35} \quad \boxed{b = -46.14}$$

$$t = a \ln k + b$$

$$t = 76.35 \ln k - 46.14$$

$$\boxed{k = 2.42}$$

$$t = 76.35 \ln 2.42 - 46.14$$

$$\boxed{t = 21.34^\circ\text{C}}$$

Qu. 17

$$R_t = R_0 (1 + 0.00393t)$$

$$t_1 = 30^\circ \quad R_{t_1} = 82 \Omega$$

$$t_2 = ? \text{ when } R_{t_2} = 95 \Omega$$

$$82 = R_0 (1 + 0.00393 \times 30) =$$

$$95 = R_0 (1 + 0.00393 \times t_2) =$$

eqn ① divided by eqn ②

$$\frac{82}{95} = \frac{R_0 (1.1179)}{R_0 (1 + 0.00393 \times t_2)}$$

$$t_2 = 75.1^\circ \text{C} = \underline{\underline{72.82^\circ \text{C}}}$$

Qu. 19

Volume = constant

$$t \propto P$$

$$t = at + b$$

$$\text{when } t = 0^\circ \text{C} \quad t = 100^\circ \text{C} \quad P = 1366 \text{ mm of Hg}$$

$$P = 1000 \text{ mm of Hg}$$

$$0 = 1000a + b$$

$$100 = 1366a + b$$

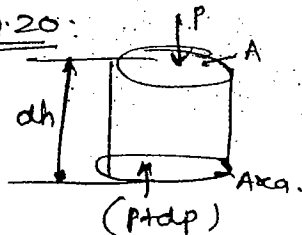
$$a = 0.273$$

$$b = -273.22$$

$$t = 0.273 \times 1074 - 273$$

$$t = \underline{\underline{20.20^\circ \text{C}}}$$

Qu. 20



$$PA - (P + dP)A = \frac{\rho g h dh}{g_c} \cdot A$$

$$-dP = \frac{\rho g}{g_c} dh$$

$$dh = -\frac{g_c}{\rho g} dP$$

$$\rho = P/RT$$

$$dh = -\frac{g_c}{P/RT} \cdot dP$$

$$= -\frac{g_c RT}{P} \frac{dP}{P}$$

$$\int dh =$$

$$h = \left[\frac{g_c RT}{P} \right]$$

$$\ln \frac{P}{P_0} =$$

$$\frac{P}{P_0} =$$

$$P = P_0$$

Qu. 1 Pg. 1

$$\Delta P = \Delta \rho$$

$$\frac{750}{7}$$

Qu. 11 Pg. 1

$$\int_0^h dh = - \int_{P_0}^P \frac{g_c R T}{g} \frac{dP}{P}$$

$$h = \left[\frac{-g_c R T}{g} \ln P \right]_{P_0}^P$$

$$\ln \frac{P}{P_0} = \frac{-gh}{g_c R T}$$

$$\frac{P}{P_0} = e^{-gh/g_c R T}$$

$$P = P_0 e^{-\frac{gh}{g_c R T}}$$

Qu. 1 Pg. 1 $P_{\text{barometer base}} = 750 \text{ mm Hg}$ $P_{\text{barometer top}} = 600 \text{ mm Hg}$

$$S = 1 \text{ kg/m}^3 \quad g = 10 \text{ m/s}^2$$

$$\Delta P = \Delta p = \frac{S g dh}{g_c}$$

$$\frac{750 - 600}{760} \times 101325 = 1 \times 10 \times dh$$

$$19998.355 = 10 dh$$

$$dh = 2000 \text{ m}$$

Qu. 11 Pg No 2

$$\frac{C - \text{Lower fixed point}}{\text{Upper fixed point} - \text{Lower fixed point}} = \frac{F - \text{LFP}}{\text{UFP} - \text{LFP}} = \frac{R - O}{\text{UFP} - \text{LFP}}$$

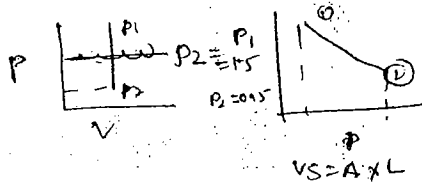
$$\frac{C - 0}{100 - 0} = \frac{F - 32}{212 - 32} = \frac{R - 0}{80 - 0} = \frac{P - \text{LFP}}{\text{UFP} - \text{LFP}}$$

$$\frac{C}{100} = \frac{0 - 300}{100 - 300}$$

$$C = 150^\circ \text{C}$$

Q.5 Pg No: 6

$$A = 0.12 \text{ m}^2, P_1 = 1.5 \text{ MPa}, P_2 = 0.15 \text{ MPa}$$



$$VS = A \times L = 0.12 \times 0.3 = 0.036 \text{ m}^3$$

work done = Area of trapezium

$$W_2 = \frac{1}{2} (P_1 + P_2) VS$$

$$= \frac{1}{2} (1.5 + 0.15) 0.036$$

$$= 0.0297$$

$$= 29.7$$

Q.7

$$Q_2 = 41187 \text{ MJ/hr}$$

me

g

Δ

type of C

Q.6

$$V_1 = 0.05 \text{ m}^3, P = 10 \text{ bar}, W.D = ?$$

$$P = 1000 \text{ kPa}$$

$$P = \frac{A}{V_2} - \frac{B}{V}$$

$$V_2 = 0.1 \text{ m}^3$$

$$P_2 = 1 \text{ bar}$$

$$= 100 \text{ kPa}$$

$$1000 = \frac{A}{(0.05)^2} - \frac{B}{(0.05)}$$

$$1000 = 400A - 20B$$

$$100 = \frac{A}{(0.1)^2} - \frac{B}{0.1}$$

$$100 = 100A - 10B$$

$$A = 4, B = 30$$

$$P = \left(\frac{4}{V^2} - \frac{30}{V} \right) \text{ kPa}$$

$$W_2 = \int_{V_1}^{V_2} P dV = \int_{0.05}^{0.1} \left(\frac{4}{V^2} - \frac{30}{V} \right) dV$$

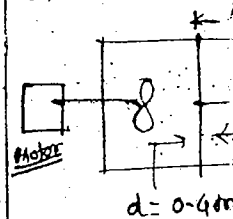
$$= \left[4 \cdot \frac{V^{-2+1}}{-2+1} \right]_{0.05}^{0.1} - (30 \ln V)_{0.05}^{0.1}$$

$$= \left[4 \left(\frac{(0.1)^{-1}}{-1} - \frac{(0.05)^{-1}}{-1} \right) \right] - 30 (\ln(0.1) - \ln(0.05))$$

$$= 40 - 20.39$$

$$= 19.61 \text{ kJ}$$

Q.9:



$$d = 0.4 \text{ m}$$

power

Q

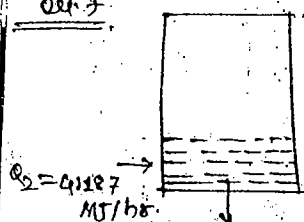
P

29.

326 m³

um

Q1.7



mass = 500 kg.

$c_p = 4.187 \text{ kJ/kgK}$

$\Delta T = 45^\circ - 5^\circ$
 $= 40^\circ\text{C}$

Heat removed from milk

$$= \text{mass} \times c_{p, \text{milk}} \times \Delta T$$

$$= 500 \times 4.187 \times 40$$

$$= 83740 \text{ kJ}$$

Net heat removal rate

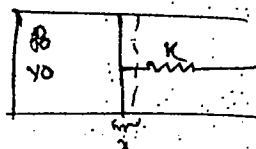
$$= Q_1 - Q_2$$

$$= 32.66 \text{ MJ/hr}$$

$$= 32,680 \text{ kJ/hr}$$

Time of cooling = $\frac{\text{heat removed from milk}}{\text{Net heat removal rate}} = \frac{83740}{32680} = 2.22 \text{ hr}$

* In a piston cylinder mechanism the initial pressure p_0 , initial volume is V_0 and c/s Area is 'A'. It is connected by a spring stiffness 'K' as shown in the figure the volume expand from V_0 to V . What is the final pressure acting on the piston.



$$\Rightarrow \alpha = \frac{V - V_0}{A}$$

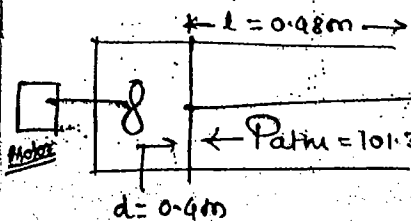
Final force = Initial force + Spring force

$$P_f A = P_0 A + Kx$$

$$= P_0 A + K \left(\frac{V - V_0}{A} \right)$$

$$P_f = P_0 + K \left(\frac{V - V_0}{A^2} \right)$$

Ex-g:



$N = 840 \text{ rpm}$

$t = 10 \text{ min}$

$$W_{\text{net}} = 2 \text{ kJ}$$

$$W_{\text{net}} = P dV - W_{\text{stirr}}$$

$$= 101.325 \times \frac{\pi}{4} \times 0.4^2 \times L - W_{\text{stirr}}$$

$$2 = 6.111 - W_{\text{stirr}}$$

$$W_{\text{stirr}} = 4.11 \text{ kJ}$$

Power of stirrer = $\frac{W_{\text{stirr}}}{\text{time}} = \frac{4.11}{1 \times 60} = 6.85 \times 10^{-3} \text{ kW}$

Ex-g

$$P = \frac{2\pi NT}{60}$$

$$T = 0.099 \text{ m}$$

Ques 10:

$$\left(p + \frac{a}{v^2}\right)(v-b) = mRT$$

$$p + \frac{a}{v^2} = \frac{mRT}{v-b}$$

$$p = \frac{mRT}{v-b} - \frac{a}{v^2}$$

$\frac{a}{v^2}$ = correction for
interaction molecule
of attraction

b = correction for
V_m occupied
by molecule.

$$W_2 = \int_{v_1}^{v_2} p dv = \int_{v_1}^{v_2} \left(\frac{mRT}{v-b} - \frac{a}{v^2} \right) dv$$

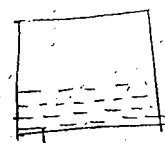
$$= \int_{v_1}^{v_2} \left[mRT \ln(v-b) \right]_{v_1}^{v_2} - a \cdot \frac{v^{-2+1}}{-2+1} \Big|_{v_1}^{v_2}$$

$$= mRT \ln \left(\frac{v_2-b}{v_1-b} \right) + a \left(\frac{1}{v_2} - \frac{1}{v_1} \right)$$

$$= -139.4165 \times 10^3 \text{ kJ}$$

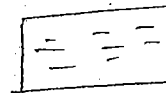
$T = 25^\circ\text{C}$
 $m = 10 \text{ kg}$
 $v_1 = 1 \text{ m}^3, v_2 = 10 \text{ m}^3$
 $T = 293 \text{ K}$
 $a = 15.7 \times 10^4 \text{ Nm}^4$
 $b = 1.07 \times 10^{-2}$
 $R = 0.278 \text{ kJ/kg}^\circ\text{K}$

Ques 11:



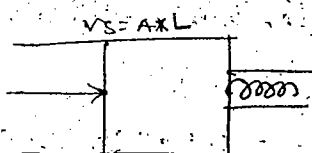
$m_w = 500$

$T_1 = 25^\circ\text{C}$



So it is an

Ques 4: 10/06/20

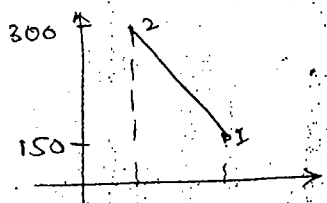


$P_1 = 150 \text{ kPa}, P_2 = 300 \text{ kPa}$

$C/S A = 220 \text{ cm}^2$

$V_S = 220 \times 10^{-4} \text{ m}^2 \times 0.2 \text{ m}$

$V_S = 4 \times 10^{-3} \text{ m}^3$

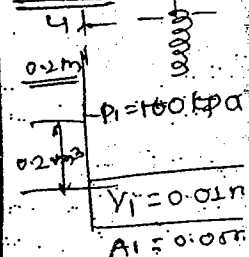


$$W_2 = \frac{1}{2} (P_1 + P_2) V_S$$

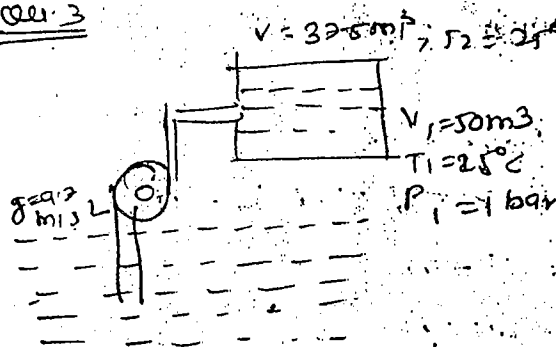
$$W_2 = 0.9 \text{ kJ}$$

$$= 909 \text{ W} \quad 90 \text{ W} \quad 3990 \text{ kJ}$$

Ques 1:



Ques 3:



$V = 37.5 \text{ m}^3, T_2 = 25^\circ\text{C}, P_2 = 2$

Volume of water (2% of air)
 $V_w = 37.5 \text{ m}^3$

$V_1 = 50 \text{ m}^3$

$T_1 = 25^\circ\text{C}$

$P_1 = 1 \text{ bar}$

$W = \text{work of pump} + \text{work of compression of air}$

$$= -\frac{mgh}{g_c} + p_1 v_1 \ln \frac{v_2}{v_1}$$

$$= -\frac{V_S g h}{g_c} + p_1 v_1 \ln \frac{v_2}{v_1}$$

$$= \frac{-37.5 \times 10^3 \times 9.81 \times 25}{1000} + 100 \times 50 \ln \frac{2}{1}$$

$$= -12731.25 \text{ W}$$

$$W = -19662.72 \text{ W}$$

Ques 11: 2/11

- Correction for
V_{air} occupied
by molecule.

$\approx 10 \text{ kg}$.

$$m^3, V_2 = 10 m^3$$

293K

$$= 7 \times 10^4 \text{ Nm}^4$$

$$1.07 \times 10^{-2}$$

278 КГП-К

$$\rho_w = 1000 \text{ kg/m}^3$$

$$\text{Volume} = \frac{m \omega}{\rho \cdot \omega}$$

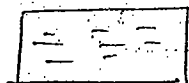
$$m_w = 500 \text{ kg} \quad V_w = 0.5 \text{ m}^3$$

$$T_1 = 25^\circ\text{C}$$

$$p_1 = 100 \text{ kPa}$$

total volume = 4 m^3

$$V_1 = 4 - 0.5 = 3.5 \text{ m}^3$$



Addition -
manuscript

$$m\omega = 1.20 \text{ kg}$$

$$\rho_w = 1000 \text{ kg/m}^3$$

$$V_w = 1 \text{ m}^3$$

$$Y_2 = 3 \text{ m}^3$$

$$\phi_2 = 9$$

$$T_2 = 25^\circ\text{C}$$

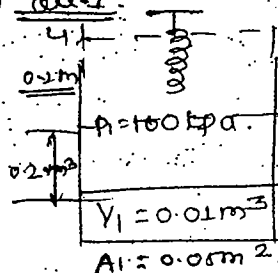
So it is an isothermal process

$$P_1 V_1 = P_2 V_2$$

$$100 \times 3.5 = P_2 \times 3$$

$$P_2 = 116.67 \text{ kPa}$$

$$W_2 = P_1 V_1 \ln \frac{V_2}{V_1} = 100 \times 35 \ln \left(\frac{3}{3.5} \right) = \underline{\underline{-53.95 \text{ J}}}$$



$$\lambda = 2.5 \text{ km/m}$$

$$V_j = A_{12}$$

$$\rightarrow y = 0.6 \text{ m}$$

$$y_2 = 3y_1$$

$$f_2 = 34$$

$$l_1 = \frac{V}{\rho_1} = \underline{\underline{0.2}}$$

$k \Delta x = k(\Delta x)_{\text{of expansion}} + (\Delta x)_{\text{on spring}}$

$$= p dr + \frac{1}{2} k r^2$$

$$= 100 \times (0.03 - 0.01) + \frac{1}{2} \times 25 \times (0.06 - 0.04)$$

$$= 2 + 0.5$$

525

Ques 11: $\int_{-1}^1 p(x) dx = \int_{-1}^1 p_m(x) dx$

120000 - 4 stroke

60,000 → 2 stroke

$$= \left(\frac{A_d}{\lambda d} \times k \right) \cdot L \cdot A \cdot N \cdot n$$

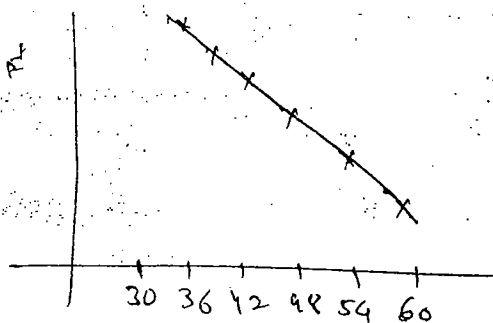
120,000

$$G = \frac{Ad}{0.11} \times 25 \times 10^6 \times 2 \times 0.7854 \times (0.15)^2 \times \frac{216}{60} \times 1$$

120,000

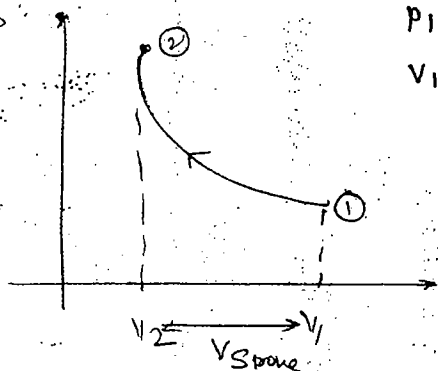
$$A_d = 0.03018 \text{ m}^2 \text{ check } \underline{\underline{503 \text{ mm}^2}} \approx \underline{\underline{602.32}}$$

X	Pg bar	Pabs = Pg + Patm	Pabs = Patm + Pg	F = P x A
60	0.0	0	101.325	$= P \times \pi \times (0.03)^2$ $= P \times 7.0686 \times 10^{-4}$
54	0.17	17	118.325	$= 0.07162$
48	0.77	77	178.325	$= 0.0836$
42	0.87	87	188.325	$= 0.12605$
56	0.95	95	196.325	$= 0.1331$
30	1.43	143	244.325	$= 0.13877$
				$= 0.1227$



The under curve is
work done.

Ques 13



$$P_1 = 101.325 \text{ kPa}$$

$$V_1 = ?$$

$$V_2 = \frac{V_1}{5}$$

$$V_2 = \pi r^2 L$$

$$V_2 - \frac{V_1}{5} = \pi r^2 L (0.1) (0.3)$$

$$V_2 - \frac{V_1}{5} = 4.4128 \times 10^{-3}$$

$$5V_2 - V_1 = 0.022$$

$$V_1 = 5.52 \times 10^{-3} \text{ m}^3$$

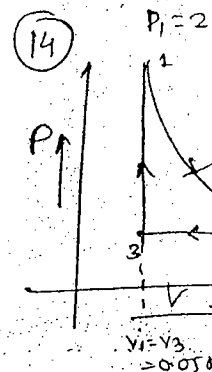
$$V_2 = \frac{V_1}{5} = 1.1044 \times 10^{-3} \text{ m}^3$$

$$W_{12} = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$W_{12} = \frac{101.325 \times 5.52 \times 10^{-3} - 699 \times 1.1044 \times 10^{-3}}{1.2-1}$$

$$= \frac{1.19}{1.064} = 1.119$$

process



process

process

Ques 15

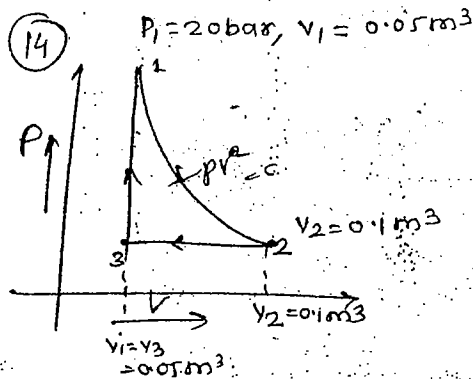


work done

7.

$$\text{power (kW)} = \text{work/shaft/cylinder} \times \text{compression ratio/cylinder} \times \text{No. of cylinders}$$

$$= 500 \times 1.06 \times \frac{500}{60} \times 0.2 = \underline{17.5 \text{ kW}}$$



process 1-2

$$pV^2 = c$$

$$P_1 V_1^2 = P_2 V_2^2$$

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^2$$

$$= 20 \left(\frac{1}{2} \right)^2$$

$$= \underline{5 \text{ bar}}$$

$$W_{12} = \frac{P_1 V_1 - P_2 V_2}{n-1} = \frac{2000 \times 0.05 - (500 \times 0.1)}{2-1}$$

$$\boxed{W_{12} = 50 \text{ kJ}} = 50$$

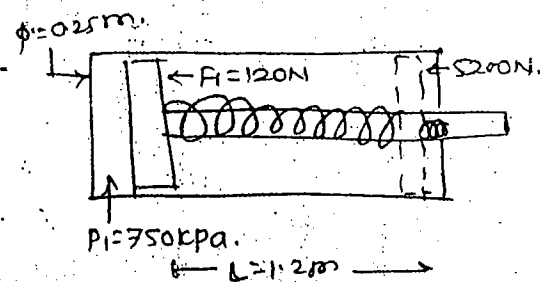
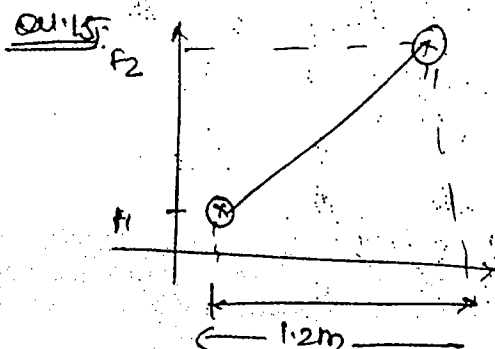
process 2-3 $p = c$

$$W_{23} = p(V_3 - V_2) = 500(0.05 - 0.1) = -25 \text{ kJ}$$

process 3-1 $V = c$

$$W_{31} = 0$$

$$W_{\text{net}} = W_{12} + W_{23} + W_{31} = 50 - 25 + 0 = \underline{25 \text{ kJ}}$$



work done = area of diagram = area of trapezium

$$= \frac{1}{2} (F_1 + F_2) s$$

$$= \frac{1}{2} (120 + 500) 1.2$$

$$= \underline{3072 \text{ kJ}}$$

$\times (0.25)$

$10^3 \cdot \text{m}^3$

10^3

$10^3 = 1.45$

1.0645

1.0645

Q.1 pg 104

$$UP = PR = RT = x$$

$$VR = QR = y$$

WVUR

$$2x \times 2y = 48$$

$$xy = 12$$

Area PST

PQR; PST are similar triangles

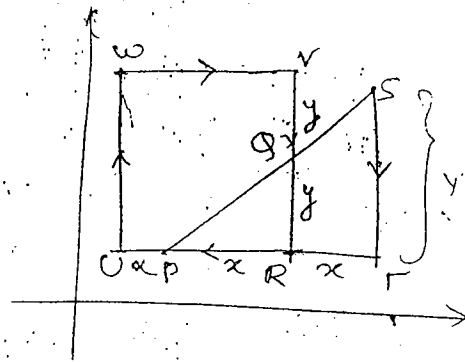
$$\frac{y}{x} = \frac{y'}{2x}$$

$$y' = 2y$$

$$\frac{1}{2} \times 2x \times 2y$$

$$= 2xy$$

$$= 2 \times 12 = 24 \text{ Nm}$$



Q.2

$$p_1 v_1 = p_2 v_2$$

Q.2

$$v_1 = 0.1 \text{ m}^3, p_1 = 1 \text{ bar}, T_1 = 25^\circ \text{C}$$

$$T_1 = 25^\circ \text{C} = 300 \text{ K}$$

$$v_2 = 0.04 \text{ m}^3$$

$$p_2 = 5 \text{ bar}$$

$$T_2 = ?$$

$$p_1 = 100 \text{ kPa}$$

$$T_1 = 300 \text{ K}$$

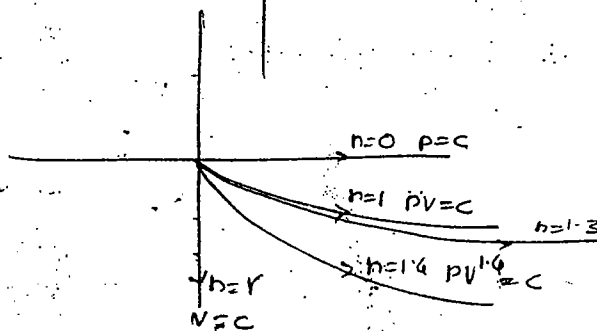
$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$$\frac{100 \times 0.1}{300} = \frac{500 \times 0.04}{T_2}$$

$$T_2 = 600 \text{ K}$$

Q.5

Area under
this work



Q.6

$$Q_S = 300 \text{ kJ}, Q_R = 100 \text{ kJ}, W_E = 300 + 250 = 550$$

$$W_C = 250 + 100 = 350$$

$$W_{net} = W_E - W_C = 550 - 350 = 200$$

$$\eta_R = \frac{W_{net}}{W_E} = \frac{200}{550} = 0.3636$$

$$\eta_{th} = \frac{W_{net}}{Q_S} = \frac{200}{300} = 66.7\%$$

Q.119

Q.1 pg 104

$$dQ = dW$$

$$dQ - dW = 0$$

insulated

Rigid

(12=11)
isothermal

$$p_1 v_1 = p_2 v_2$$

$$20 \times 15 = p_2 \times 15$$

$$p_2 = 20$$

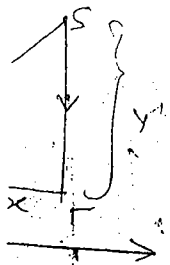
Q.2

$$h_1$$

$$h_2$$

insulated

rigid cylin
free expansion



Q.8:

$$P_1 V_1 = P_2 V_2 \quad \therefore P_1 V_1 = \frac{P_1}{10} \times 0.55$$

$$V_1 = 0.055 \text{ m}^3$$

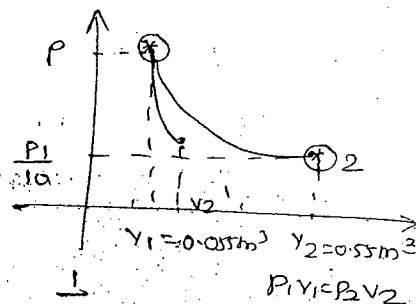
$$V_2' = ?$$

$$P_1 V_1^{\gamma} = P_2 V_2'^{\gamma}$$

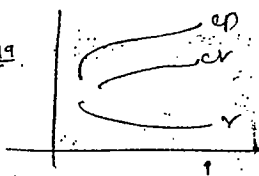
$$\left(\frac{V_2'}{V_1} \right)^{\gamma} = \frac{P_1}{P_2}$$

$$V_2' = V_1 \left(\frac{P_1}{P_2} \right)^{1/\gamma} = 0.055 \left(\frac{P}{P/10} \right)^{1/1.4}$$

$$= 0.28$$



Q.19



$$P_2 = 5 \text{ bar}$$

Q.1 pg No 3

1st Law Thermodynamic

$$dQ = dW = dU$$

$$dQ - dW = C_v dT$$

$$\text{insulated } dQ = 0$$

$$\text{Rigid } dW = 0$$

$$(C_1 = T_1) \quad dT = 0$$

isothermal

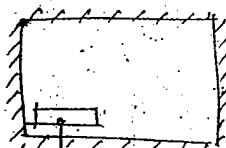
$$P_1 V_1 = P_2 V_2$$

$$20 \times 15 = P_2 \times 1500$$

$$P_2 = 0.2 \text{ atm}$$

$$V_2 = 1500 \text{ c.c.}$$

$$P_0 = 0$$



$$P = 20 \text{ atm}$$

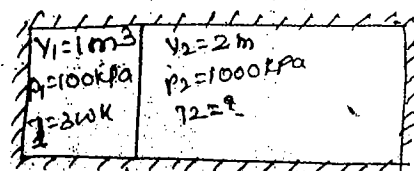
$$V_1 = 15 \text{ c.c.}$$

$$T_1 = 40^\circ \text{C}$$

Q.12

$$n_1 = \frac{P_1 V_1}{RT_1} = \frac{100 \times 1}{8.314 \times 300} = 0.04$$

$$n_2 = \frac{P_2 V_2}{RT_2} = \frac{100 \times 2}{8.314 \times 1000} = 0.24$$



mixed both

$$V_f = 1 + 2 = 3 \text{ m}^3$$

$$n_f = n_1 + n_2 = 0.28 \text{ mol}$$

$$P_f = ? \quad T_f = ?$$

$$\text{insulated } dQ = 0$$

rigid cylinder

$$\text{free expansion } dW = 0$$

$$dU = 0$$

$$(dU)_I + (dU)_II = 0$$

$$n_1 C_v (T_f - T_1) + n_2 C_v (T_f - T_2) = 0$$

$$n_1 C_v (T_f - T_1) = n_2 C_v (T_2 - T_f)$$

$$= 0.04(T_f - 300) = 0.24(1000 - T_f)$$

$$0.04T_f - 12 = 240 - 0.24T_f$$

$$0.04T_f + 0.24T_f = 240 + 12$$

$$T_f = 900 \text{ K}$$

$$P_f = \frac{nRT_f}{V_D} = \frac{0.28 \times 8.314 \times 900}{3} = 700 \text{ kPa} = 0.7 \text{ MPa}$$

au.3

$$P_1 = P_2 = 1.4 \text{ bar}$$

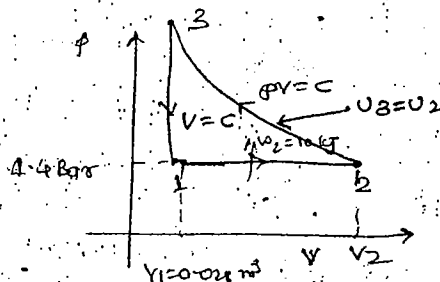
$$V_1 = 0.028 \text{ m}^3$$

$$W_2 = 10 \text{ kJ}$$

$$U_1 - U_3 = -26.4 \text{ kJ}$$

$$U_1 - U_2 = -26.4 \text{ kJ}$$

$$U_3 = U_2$$



1-2 $P=C$

$$W_2 = P(V_2 - V_1)$$

$$10.5 = 140(V_2 - 0.028)$$

$$10.5 = 140V_2 - 3.92$$

$$V_2 = 0.103 \text{ m}^3$$

$$Q_2 - W_2 = \Delta U_2$$

$$Q_2 - 10.5 = U_2 - U_1 = -(U_1 - U_2)$$

$$Q_2 - 10.5 (U_2 - U_1) = -(-26.4)$$

$$= 26.4$$

$$Q_2 = 36.9 \text{ kJ}$$

2-3 $T=C$

$$Q_3 = W_3 = P_2 V_2 \ln \frac{V_3}{V_2}$$

$$P_2 V_2 \ln \frac{V_3}{V_2} = 140 \times 0.103 \ln \left(\frac{0.028}{0.103} \right)$$

$$= -10.134 \text{ kJ} \quad -18.382 \text{ kJ}$$

3-1 $V=C$ $dW=0$

$$Q_1 - W_1 = \Delta U_1$$

$$Q_1 = \Delta U_1$$

$$Q_1 = U_1 - U_3 = 26.4 \text{ kJ}$$

$$\Sigma Q = 1Q_2 +$$

$$\Sigma W = 1W_2 +$$

$$\Sigma Q =$$

au.4

sta

process

au.5

SFEE

m

$$\Sigma Q = 1Q_2 + 2Q_3 + 3Q_1 = 36.9 + 18.78 - 26.3 = -8.28 \text{ kJ}$$

$$\Sigma W = 1W_2 + 2W_3 + 3W_1 = 10.5 + 18.78 + 0 = -8.28 \text{ kJ}$$

$$\Sigma Q = \Sigma W \quad \text{1st law proved}$$

Q1.4:

State 1-2

$$1Q_2 - 114_2 = 1E_2 = E_2 - E_1$$

$$1Q_2 - P(V_2 - V_1) = E_2 - E_1$$

$$1Q_2 - 100(0.3 - 0.003) = E_2 - 0$$

$$0 - 29.7 = E_2$$

$$E_2 = -29.7 \text{ kJ}$$

Process 2-3

$$2Q_3 - 2W_3 = E_3 - E_2$$

$$2Q_3 - P(V_3 - V_2) = E_3 - (-29.7)$$

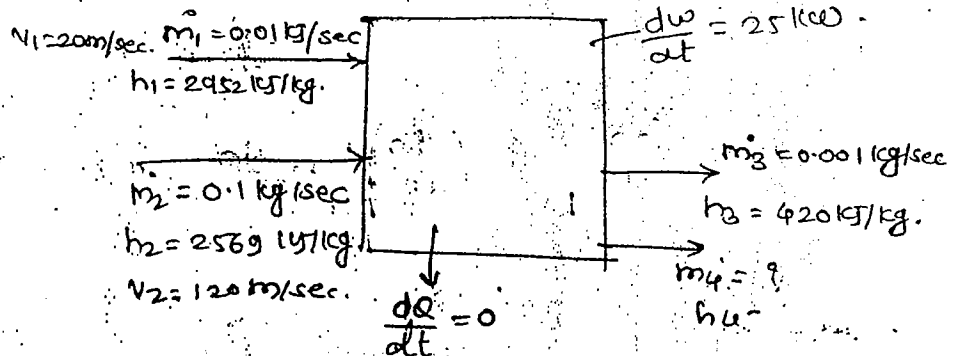
$$2Q_3 + 24 - 100(0.06 - 0.3) = E_3 + 29.7$$

$$2Q_3 + 24 = E_3 + 29.7$$

$$-105 + 24 = E_3 + 29.7$$

$$E_3 = -110.7 \text{ kJ}$$

Q1.5



SFEE

Mass balance

$$m_1 + m_2 = m_3 + m_4$$

$$0.01 + 0.1 = 0.001 + m_4$$

$$m_4 = 0.109 \text{ kg/sec}$$

Energy entering = Energy leaving

$$m_1 \left(h_1 + \frac{V_1^2}{2000} \right) + m_2 \left(h_2 + \frac{V_2^2}{2000} \right) + \frac{dQ}{dt} = m_3 \left(h_3 + \frac{V_3^2}{2000} \right) + m_4 \left(h_4 + \frac{V_4^2}{2000} \right) + \frac{dW}{dt}$$

$$\Rightarrow 0.01 \left(2952 + \frac{20 \times 10^3}{2000} \right) + 0.1 \left(2569 + \frac{120^2}{2000} \right) + 0 =$$

$$0.001 \times 420 + 0.109 h_4 + 25$$

$$29.52 + 257.62 = 0.42 + 0.109 h_4 + 25$$

$$287.14 = 25.42 + 0.109 h_4$$

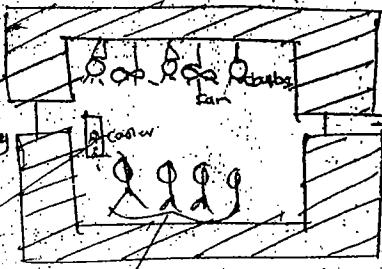
$$261.72 = 0.109 h_4$$

$$h_4 = 2401.1 \text{ kJ/kg}$$

Q1.6

$$\dot{m} = 80 \text{ kg/hr}$$

$$h_1 = 84 \text{ kJ/kg}$$



$$\left(\frac{dQ}{dt} \right)_{\text{bulbs}} = -3 \times 0.1 = -0.3 \text{ kW}$$

$$\dot{m} = 80 \text{ kg/hr} \quad h_2 = 59 \text{ kJ/kg}$$

$$\left(\frac{dQ}{dt} \right)_{\text{fans}} = -2 \times 0.18 = -0.36 \text{ kW}$$

$$\left(\frac{dQ}{dt} \right)_{\text{person}} = 4 \times 620 \text{ kJ/hr} = 2520 \text{ kJ/hr}$$

$$\left(\frac{dQ}{dt} \right)_{\text{bulb}} + \left(\frac{dQ}{dt} \right)_{\text{fan}} = -0.66 \text{ kW}$$

$$\left(\frac{dQ}{dt} \right)_{\text{room cooler}} =$$

SFEE

$$\dot{m} h_1 + \left(\frac{dQ}{dt} \right)_{\text{person}} + \left(\frac{dQ}{dt} \right)_{\text{room cooler}} + \frac{dQ}{dt} = \dot{m} h_2 + \frac{dQ}{dt}$$

$$\frac{80 \times 84 + 2520}{3600} + \left(\frac{dQ}{dt} \right)_{\text{r.c.}} = \frac{80 \times 59}{3600} - 0.66$$

$$2521.86 + \left(\frac{dQ}{dt} \right)_{\text{r.c.}} = 0.6511$$

$$\left(\frac{dQ}{dt} \right)_{\text{r.c.}} = -1.91 \text{ kW}$$

Q1.7

CV

dQ

= [

= a

Q1.8

p =

p1

p1 =

1000 =

p2 =

200 kg

a

p =

1 w2 =

=

= 1

=

=

U = \sum

= (

=

U

Q. 7

$$cv = a + bt + ct^2$$

$$dQ = \int_{T_1}^{T_2} cv dT = \int_{T_1}^{T_2} (a + bt + ct^2) dT$$

$$= \left[at \right]_{T_1}^{T_2} + \left(\frac{bT^2}{2} \right)_{T_1}^{T_2} + \left(\frac{cT^3}{3} \right)_{T_1}^{T_2}$$

$$= a(T_2 - T_1) + \frac{b}{2} (T_2^2 - T_1^2) + \frac{c}{3} (T_2^3 - T_1^3)$$

Q. 8

$$p = a + bv$$

$$p_1 = 1000 \text{ kPa}$$

$$p_2 = 2000 \text{ kPa}$$

$$v_1 = 0.20 \text{ m}^3$$

$$v_2 = 0.120 \text{ m}^3$$

$$p_1 =$$

$$p_1 = a + bv_1 \quad \text{--- (1)}$$

$$1000 = a + b \times 0.20$$

$$p_2 = a + bv_2$$

$$2000 = a + b \times 0.120$$

$$\boxed{a = 1160} \quad \boxed{b = -800}$$

$$p = 1160 - 800v$$

$$W_2 = \int_{v_1}^{v_2} p dv$$

$$= \int_{0.2}^{0.12} (1160 - 800v) dv$$

$$= \left[1160v - 800 \frac{v^2}{2} \right]_{0.2}^{0.12}$$

$$= 1160(0.12 - 0.2) - 800 \left(\frac{0.12^2}{2} - \frac{0.2^2}{2} \right)$$

$$= 1160 - 560$$

$$= \underline{600 \text{ kJ}}$$

$$U = \left\{ 1.5 p v - 85 \right\} \text{ kJ/kg}$$

$$= \left(1.5 p \frac{V}{m} - 85 \right) \text{ kJ/kg}$$

$$= 1.5 \times (p v - 85) \text{ kJ/kg}$$

$$u_1 = p_1 v_1 - 85$$

$$= 1000 \times 0.20 - 85$$

$$= 115 \text{ kJ/kg}$$

$$u_2 = p_2 v_2 - 85 = \underline{155 \text{ kJ/kg}}$$

$$m = 1.5$$

$$\Delta U = u_2 - u_1$$

$$= 155 - 115$$

$$= 40 \text{ kJ/kg}$$

$$\text{change in } \Delta U$$

$$= 40 \times 1.5$$

$$= 60 \text{ kJ}$$

$$q + 25$$

$$= -0.3 \text{ kW}$$

$$\text{kg}$$

$$= -0.36 \text{ kW}$$

$$= -0.66 \text{ kW}$$

$$\frac{dw}{dt}$$

$$aQ - aW = u \quad \dots \quad 14 - 000 - 00$$

$$\boxed{dQ = 60 + 600 = 660 \text{ kJ}}$$

$$U = (pv - 85) \text{ kJ/kg}$$

$$p = a + bv$$

$$U = (a + bv)v - 85$$

$$U = av + bv^2 - 85 \text{ kJ/kg}$$

$$U = \text{function of } v \text{ only}$$

$$\frac{dU}{dv} = a + 2bv = 0$$

$$v = -\frac{a}{2b} = \frac{-1160}{2 \times (-800)} = 0.725 \text{ m/s}$$

$$U_{\max} = 1160 \times 0.725 - 800 \times (0.725)^2 - 85$$

$$= 84 - 420.5 - 85$$

$$= 335.5 \text{ kJ/kg}$$

$$U_{\max} = 1.5 \times 335.5$$

$$= 503.25 \text{ kJ}$$

or

$$U = pv - 85$$

$$p = a + bv$$

$$b \cdot v = \frac{p - a}{b}$$

$$U = \frac{p(p-a)}{b} - 85 = \frac{p^2}{b} - \frac{ap}{b} - 85 = f(p)$$

$$\frac{dU}{dp} = \frac{2p}{b} - \frac{a}{b} = 0 \quad \boxed{p = a/2}$$

$$p = \frac{1160}{2} = 580$$

$$U_{\max} = \frac{580^2}{-800} - \frac{1160 \times 580}{-800} - 85$$

$$= -420.5 + 841 - 85 = 335.5 \text{ kJ/kg}$$

$$= 503.25 \text{ kJ} =$$

$$(U_{\max})_{\text{actual}} = 1.5 \times 335.5$$

$$= 503.25 \text{ kJ}$$

or

$$A = 0.1 \text{ m}^2$$

$$V_1 = 0.18 \frac{\text{m}^3}{\text{s}}$$

$$h_1 = 3000 \text{ kJ/kg}$$

$$V_1 = 60 \text{ m/sec}$$

$$V_2 =$$

$$V_2 =$$

$$\boxed{V_2 =}$$

$$m =$$

$$A_2$$

$$V_2$$

$$\underline{0.10}$$

$$m \text{ (hit)}$$

$$0.42$$

Q.9

$A_1 = 0.1 \text{ m}^2$
 $V_1 = 0.18 \frac{\text{m}^2}{\text{kg}}$
 $h_1 = 3000 \text{ kJ/kg}$
 $V_1 = 60 \text{ m/sec}$
 $\frac{dQ}{dt} = 0$
 $\frac{dw}{dm} = 0$
 $h_2 = 2962 \text{ kJ/kg}$
 $V_2 = ?$
 $A_2 = ?$
 $h_2 = 2962 \text{ kJ/kg}$
 $V_2 = 0.498 \text{ m}^2/\text{kg}$

$$V_2 = \sqrt{V_1^2 + 2000(h_1 - h_2)}$$

$$V_2 = \sqrt{(60)^2 + 2000(3000 - 2962)}$$

$$V_2 = 692.53 \text{ m/sec}$$

$$\dot{m} = \frac{A_1 V_1}{V_1} = \frac{0.1 \times 60}{0.182} = 32.98 \text{ kg/sec}$$

$$\frac{A_2 V_2}{V_2} = \frac{A_2 \times 692.5}{0.498} = 32.98$$

$$A_2 = 0.023 \text{ m}^2$$

Q.10

$\dot{m} \text{ (kg/sec)}$
 $h_1 = 2785 \text{ kJ/kg}$
 $V_1 = 33.33 \text{ m/sec}$
 $z_1 = 3 \text{ m}$

$$\frac{dQ}{dt} = -0.29 \text{ kW}$$

$$\dot{m} = 0.42 \text{ kg/s}$$

$h_2 = 2512 \text{ kJ/kg}$
 $V_2 = 100 \text{ m/sec}$
 $z_2 = 0$

$$\dot{m} \left(h_1 + \frac{V_1^2}{2000} + \frac{z_1 g}{1000} \right) + \frac{dQ}{dt} = \dot{m} \left(h_2 + \frac{V_2^2}{2000} \right) + \frac{dw}{dt}$$

$$0.42 \left(2785 + \frac{33.33^2}{2000} + \frac{3 \times 9.81}{1000} \right) + (-0.29) = 0.42 \left(2512 + \frac{(100)^2}{2000} \right) + \frac{dw}{dt}$$

$$1169.655 = 1072.14 + \frac{dw}{dt}$$

$$\frac{dw}{dt} = 112.51 \text{ kJ}$$

Qu. 11

$$C_p = \left(2.093 + \frac{41.87}{t+100} \right) \text{ J}^\circ\text{C}$$

$$Q = \int_{T_1}^{T_2} C_p dT$$

$$= \int_0^{100} \left(2.093 + \frac{41.87}{t+100} \right) dt$$

$$= \left(2.093T + 41.87 \ln(t+100) \right)_0^{100}$$

$$= 2.093(100) + 41.87 \ln(100+100 - (0+100))$$

$$= 238.32 \text{ J}$$

$$W = PdV$$

$$= 101.325 (V_2 - V_1)$$

$$= 101.325 (2000 - 2000) \times 10^{-6}$$

$$= \underline{40.5 \text{ J}}$$

$$Q - W = U$$

$$U = 197.825 \text{ J}$$

Qu. 12 - P4 No. 11

1-2

$$Q_2 - W_2 = U_2 - U_1$$

$$100 - 100 = U_2 - U_1$$

$$U_2 - U_1 = 0$$

$$U_2 = U_1$$

2-3

$$Q_3 - W_3 = U_3 - U_2$$

$$-150 - 2W_3 = U_3 - U_2$$

$$-150 - 2W_3 = U_3 - U_2 = U_3 - U_1 = 200$$

$$-2W_3 = 350$$

$$2W_3 = -350$$

Qu. 13

$$dQ - dW =$$

$$\delta - \text{power} \times t$$

$$- (-pt) =$$

$$50 \times 20 =$$

$$1000 =$$

$$T_2 =$$

$$V_2 =$$

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

$$\frac{100}{200} =$$

$$P_2 =$$

n degrees

CV

$$\frac{C_p}{C_v} = \left(\frac{r}{1} \right)$$

$$\underline{Q_4}: 3Q_4 - 3W_4 = 3Q_4$$

$$3Q_4 + 250 = 3Q_4$$

$$3Q_4 + 250 = U_4 - U_3$$

$$3Q_4 + 250 = (U_4 - U_1) - (U_3 - U_1) \\ = -50 - 200 = -250$$

$$\boxed{3Q_4 = -500 \text{ kJ}}$$

$$\underline{Q_1}: 4Q_1 - 4W_1 = 4Q_1$$

$$4Q_1 - 300 = U_1 - U_4 = 50$$

$$\boxed{4Q_1 = 350}$$

$$\Sigma Q = 1Q_2 + 2Q_3 + 3Q_4 + 4Q_1 \\ = 100 - 150 - 500 + 350 = -200 \text{ kJ}$$

$$\Sigma W = 1W_2 + 2W_3 + 3W_4 + 4W_1 \\ = 100 - 350 - 250 + 300 = -200 \text{ kJ}$$

$$\Sigma Q = \Sigma W \quad \text{1st law is proved.}$$

Qu: 13

$$dQ - dW = dU$$

$$\begin{aligned} \text{Q} - \text{power} \times \text{time} &= CV dT \\ \text{External work done on system, take -ve} \\ -(-pt) &= nCVdT \end{aligned}$$

$$50 \times 20 = 1 \times 20.785 \ln(T_2 - T_1)$$

$$800.0 = 20.785 (T_2 - 300)$$

$$\boxed{T_2 = 588.66 \text{ K}}$$

$$\underline{V = C}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{100}{200} = \frac{P_2}{588}$$

$$\boxed{P_2 = 196.223 \text{ kPa}}$$

Motor

$$P = 50 \text{ kW}$$

$$t = 2 \text{ min}$$

$$= 120 \text{ s}$$

$$\begin{aligned} T_1 &= 300 \text{ K} \\ CV &= 20.785 \\ J &= \text{J/mol/K} \end{aligned}$$

Qu: 5 pg No 18

Degree of freedom

Molecule ex. translⁿ Rotational total.

Monoatomic He 3 0 3

Diatomc O₂ 3 2 5

Polyatomic CH₄ 3 3 6

$$CV$$

$$CP = CV + R$$

$$\frac{3}{2} R$$

$$\frac{3}{2} R + R = \frac{5}{2} R$$

$$\frac{5}{2} R$$

$$\frac{5}{2} R + R = \frac{7}{2} R$$

$$3R$$

$$3R + R = 4R$$

n degree of freedom

$$CV = \frac{n}{2} R \quad CP = \frac{n}{2} R + R = \left(\frac{n}{2} + 1\right) R = \left(\frac{n+2}{2}\right) R$$

$$\frac{CP}{CV} = \frac{\left(\frac{n+2}{2}\right) R}{\left(\frac{n}{2}\right) R} = \left(\frac{n+2}{n}\right) \left(\frac{2}{n}\right) = \frac{n+2}{n} = \boxed{1 + \frac{2}{n}}$$

14

$$bsfc = \frac{\dot{m}_f \text{ (kg/hr)}}{bp \text{ (kW)}}$$

$$= \frac{\dot{m}_f}{26} = 0.3$$

$$\dot{m}_f = 7.8 \text{ kg/hr}$$

$$\dot{m}_a = 14 \dot{m}_f = 109.2 \text{ kg/hr}$$

$$\dot{m} = \dot{m}_a + \dot{m}_f = 117 \text{ kg/hr} = \frac{117}{3600} = 0.0325 \text{ kg/sec}$$

$$\dot{m} h_1 + \frac{dQ}{dt} = \dot{m} h_2 + \frac{dW}{dt}$$

$$\dot{m} (h_2 - h_1) = \frac{dQ}{dt} - \frac{dW}{dt}$$

$$0.0325 (h_2 - h_1) = -25.26$$

$$(h_2 - h_1) = \Delta h = \frac{-61}{0.0325} = -1877 \text{ kJ/kg}$$

Q15

$$1 \text{ cm on X axis} = 300 \text{ kPa}$$

$$1 \text{ cm on y axis} = 0.1 \text{ m}^3/\text{kg}$$

$$1 \text{ cm}^2 = (100) \times (100) \text{ } \mu\text{m}^2$$

$$= 300 \times 0.1$$

$$= 30 \text{ kJ/kg}$$

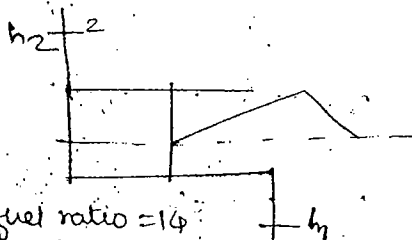
$$W = \frac{\pi}{4} (D)^2 \times \pi/4 (D)^2 = \frac{\pi}{4} (D)^2 \times \pi/4 (D)^2 = 78.5 \text{ cm}^2$$

$$= 78.5 \times 30 = 2356 \text{ W/kg}$$

$$Q_R = 100 \text{ kJ/kg}$$

$$Q_S = W + Q_R = 2456 \text{ W/kg}$$

$$\eta_R = \frac{W}{Q_S} = \frac{2356}{2456} \times 100 = 96.16\%$$



Air fuel ratio = 14
specific fuel consumption = 0.3 kg/kWhr

pg. 40 (8) Q12

$$h_1 + \frac{dQ}{dm} + \frac{dW}{dm}$$

$$= h_2 + \frac{dW}{dm}$$

$$\left(\frac{dQ}{dm} \right)_{\text{air}} =$$

$$\frac{dQ}{dt}$$

∴ M

$$\frac{dM}{dt} = 0$$

hence at point for

$$Q16: E =$$

$$dW =$$

$$E_2 - E_1$$

$$(E_2 -$$

$$dQ - dW$$

$$dQ - dW$$

Q17 1st case

2nd case

3rd case

4th case

pg. no 8 Q.1

$$dQ - dW = du$$

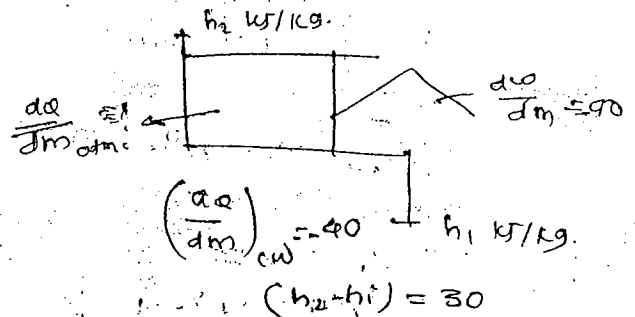
pg. no 8 Q.2

$$h_1 + \left(\frac{dQ}{dm}\right)_{cw} + \left(\frac{dQ}{dm}\right)_{air}$$

$$= h_2 + \frac{dW}{dm}$$

$$\left(\frac{dQ}{dm}\right)_{air} = (h_2 - h_1) + \frac{dW}{dm} - \frac{dQ}{dm}$$

$$= 30 - 90 - (-40) = -20 \text{ kJ heat is rejected.}$$



$$\text{Q.5 } \frac{dT}{T} - \frac{v dp}{T} \quad \therefore \frac{dT}{T} - \frac{R dp}{P}$$

$$\therefore M dx + N dy \quad M = \frac{1}{T} \quad N = -\frac{R}{P}$$

$$\frac{\partial M}{\partial P} = 0 \quad \frac{\partial N}{\partial T} = 0 \quad \therefore \frac{\partial M}{\partial P} = \frac{\partial N}{\partial T}$$

hence it is exact differential at point (h, v, T, P) represent a point function.

Q.6: $E = 25 + 0.25t \text{ kJ}$

$$dW = 0.75 \text{ kN}\cdot\text{m}$$

$$E_2 - E_1 = E_1 = 25 + 0.25t_1, \quad E_2 = 25 + 0.25t_2$$

$$(E_2 - E_1) = 0.25(t_2 - t_1) = 0.25 \times 1 = 0.25 \text{ kJ}$$

$$dQ - dW = dU$$

$$dQ - 0.75 = 0.25 \quad \boxed{dQ = 1 \text{ kJ}}$$

Q.7 1st case (rigid) $Q = 0$ $W = 0$ $U = -ve$

2nd case $Q = 0$ $W = +ve$ $U = -ve$

3rd case $Q = 0$ $W = 0$ $U = 0$

4th case $Q = 0$ $W = -ve$ $U = +ve$

Ques 8

at A < B

$$AQ_B - A^W_B = A^U_B$$

$$190 - 130 = 50 = U_B - U_A$$

ADB

$$AQ_B - A^W_B = A^U_B$$

$$AQ_B - A^W_B = U_B - U_A$$

$$AQ_B - 40 = 50$$

$$AQ_B = 90 \text{ kJ}$$

what is change in path in AB

Path AB: $A^W_B = 85$ $A^U_B = 50$

$$AQ_B - A^W_B = A^U_B$$

$$AQ_B - 50 = 80$$

$$AQ_B = 135 \text{ kJ}$$

Ques 10

Apply SFEE

$$\dot{m}h_1 + \dot{m} \frac{dQ}{dm} = \dot{m}h_2 + \dot{m} \frac{dW}{dt}$$

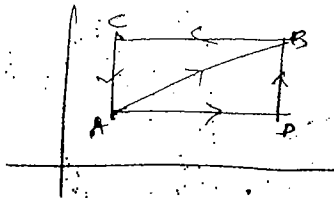
$$\frac{dW}{dt} = \dot{m}(h_1 - h_2) + \dot{m} \frac{dQ}{dm}$$

$$= 0.5(100 - 200) + 0.5 \times (-40)$$

$$= \underline{\underline{-20 - 20}}$$

Ques 11:

$$W = 4748 - 474 - 180 = 294 \text{ kJ/min} = \frac{294}{60} = 4.9 \text{ kW}$$



pg no 5

Ques pg No 5

$$p_{abs} = 101$$

$$V_1 = 25$$

$$m = \frac{p_1}{R}$$

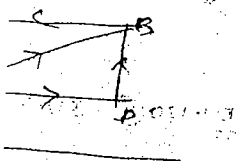
$$\text{Volume} =$$

$$\frac{201}{28}$$

$$p_{gauge}$$

$$\text{for } V =$$

$$P =$$



Pg. No 51, ex. 13

$$\left(p_1 + \frac{\rho}{\gamma_1^2}\right) \gamma_1 = \left(p_2 + \frac{\rho}{\gamma_2^2}\right) \gamma_2$$

$$\left(10 + \frac{\rho}{12}\right) 1 = \left(p_2 + \frac{\rho}{2}\right) 2$$

$$p_2 = 5 + \frac{\rho}{2}$$

because ρ is +ve

$$p_2 > p_1$$

Ans (b)

Ques Pg No 53 ex. 24 & 25

$$p_{abs} = p_{atm} + p_g$$

$$p_{abs} = 101.325 + 100 = 201.325 \text{ kPa}$$

$$\gamma_1 = 2500 \text{ cm}^3 \quad T_1 = 288 \text{ K}$$

$$m = \frac{p_1 \gamma_1}{R T_1} = \frac{201.325 \times 2500 \times 10^{-6}}{0.287 \times 288} = 6.08 \text{ gms} = 6.08 \times 10^{-3} \text{ kg}$$

Volume = constant

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\frac{201.325}{288} = \frac{p_2}{278}$$

$$p_2 = 194.334 \text{ kPa}$$

$$p_{gauge} = 194.334 - 101.325 = 93 \text{ kPa}$$

For VEC $dw = 0$

$$dQ = du$$

$$dQ = m c_v dT$$

$$= 6.08 \times 10^{-3} \times 0.718 \times (15-5)$$

$$= 0.0436 \text{ kJ}$$

$$= 43.6 \text{ J}$$

(2)

$$p_1 = ? \quad T_1 = 288 \quad T_2 = 201.325, \quad T_2 = 278$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\frac{p_1}{288} = \frac{p_2}{278}$$

$$\frac{p_1}{288} = \frac{201.325}{278}$$

$$p_1 = 208.24 \text{ kPa}$$

$$p_g = 208.24 - 101.325$$

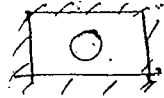
$$= 106.915 \text{ kPa}$$

$$-\frac{dw}{dt}$$

$$300 \text{ kg}$$

kw

pg 50 Qu. 33

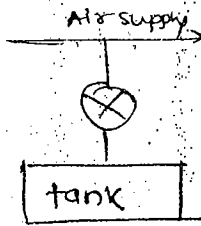


$$dQ=0 \quad dW=0$$

$$\Rightarrow dU=0 \Rightarrow cvdT=0$$

$$\Rightarrow \underline{dT=0} \Rightarrow T_2=T_1$$

Qu. 34:



$m_0=0$ initial evaluated

$$P_i=1 \text{ MPa} \quad T_i=300^\circ\text{C}$$

insulated tank $Q=0$

$m_0=0$ } charging process
 $Q=0$

$$T_f = \gamma T_i$$

$$= \underline{T_b > 350^\circ\text{C}}$$

II^o 4 La

TER $\Rightarrow$ T

Any amount of change

Hot

Hot source:

fs does not

eg: Sun, TV

Cold sink

temp does

eg: Atmos

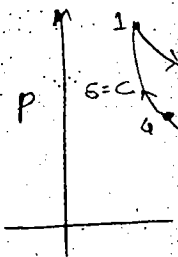
Mt MER $\Rightarrow$

eg: spring

whenever

cannot cy

Carnot cy



In the pr

IInd Law of thermodynamic

TER $\Rightarrow$ Thermal energy reservoir

Any amount of heat withdrawn from heat ^{source} any amount of heat is supplied to heat if temp does not change then it is said to be a reservoir



Hot source: any amount of heat is withdrawn if the temp is does not change then it is called as hot source.

eg: Sun, furnace,

Cold sink: Any amount of heat is rejected to it if the temp does not change then it is called as cold sink

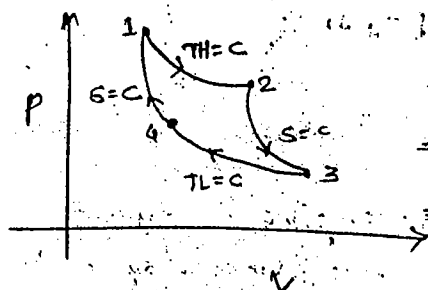
eg: Atmosphere, river water, sea water, condenser

MER $\Rightarrow$ Mechanical energy reservoir

eg: spring in watch, flywheel for an engine

Whenever we talk of heat engine we talk of Carnot cycle

Carnot cycle



1-2 Reversible isothermal heat supplied

2-3 Reversible adiabatic expansion

3-4 Reversible isothermal heat rejection

4-1 Reversible adiabatic compression

In the process 1-2 isothermal $T=C$

$$P_1 V_1 = P_2 V_2$$

$$|Q_2| = |W_2| = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= R T_H \ln \frac{V_2}{V_1} \quad \text{--- (1)}$$

process 2-3 : Reversible adiabatic expansion

$$P_2 V_2^\gamma = P_3 V_3^\gamma, \quad T_2 V_2^{\gamma-1} = T_3 V_3^{\gamma-1}$$

$$T_2 P_2^{\frac{1-\gamma}{\gamma}} = T_3 P_3^{\frac{1-\gamma}{\gamma}}$$

$$\frac{T_2}{T_3} = \left(\frac{V_3}{V_2}\right)^{\gamma-1} = \frac{T_H}{T_L}$$

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} = \frac{T_H}{T_L}$$

$$\frac{V_3}{V_4} = \frac{V_2}{V_1}$$

$$2W_3 = \frac{P_2 V_2 - P_3 V_3}{\gamma - 1} = \frac{R(T_2 - T_3)}{\gamma - 1} = C_V(T_2 - T_3) \quad \text{--- (2)}$$

process 3-4 $T = C$

$$P_3 V_3 = P_4 V_4$$

$$3Q_4 = 3W_4 = P_3 V_3 \ln\left(\frac{V_4}{V_3}\right) \text{ or}$$

$$= P_3 V_3 \ln\left(\frac{V_3}{V_4}\right)$$

$$= RT_L \ln \frac{V_3}{V_4}$$

process 4-1 : Reversible adiabatic compression

$$P_4 V_4^\gamma = P_1 V_1^\gamma$$

$$T_4 V_4^{\gamma-1} = T_1 V_1^{\gamma-1}$$

$$T_4 P_4^{\frac{1-\gamma}{\gamma}} = T_1 P_1^{\frac{1-\gamma}{\gamma}}$$

$$4W_1 = \frac{P_4 V_4 - P_1 V_1}{\gamma - 1} = \frac{R(T_4 - T_1)}{\gamma - 1} = C_V(T_4 - T_1) = C_V(T_L - T_H)$$

$$\eta_{\text{thermal}} = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S} = \frac{RT_H \ln \frac{V_2}{V_1} - RT_L \ln \frac{V_3}{V_4}}{RT_H \ln \frac{V_2}{V_1}}$$

$$= \frac{T_H - T_L}{T_H} \because \left(\frac{V_3}{V_4} = \frac{V_2}{V_1}\right)$$

The thermal efficiency of Carnot engine is depend only on temp limits but does not depend upon the medium

Kinet is 1e but thermic can have a efficiency. practical as
 ① Isotherm process is heat supply during oc and this mechanism not possible
 ② during 1 engine adiabatic and this material hence it

used for

$$\eta = 1 - \frac{T_L}{T_H}$$

$$\left(\frac{d\eta}{dT_L}\right)$$

changing when cor

$$\frac{V_3}{V_4} = \frac{V_2}{V_1}$$

$$\eta = \frac{T_H - T_L}{T_H}$$

$$\eta = \frac{T_H - T_L}{T_H}$$

$$(T_2 - T_3) - (2)$$

Carnot engine having double expansion process
 that is less stroke volume is high and m.e.p is less
 but thermal efficiency is maximum and no engine
 can have an efficiency greater than or equal to Carnot
 efficiency. Carnot engine is only theoretical engine not
 practical engine because of following reasons.

① Isothermal process is a very very slow process. Adiabatic
 process is a very very fast process. During isothermal
 heat supplied the engine should run very very slowly
 during adiabatic expansion it should run very very fast
 and this is to be done automatically. and there is no
 mechanism which can run like this hence Carnot is
 not possible engine.

② During isothermal heat supplied process the head of the
 engine should act as a perfect conductor. During
 adiabatic expansion it should act as perfect insulator
 and this should happen automatically. and there is no
 material in the universe which can operate like this
 hence it is an impossible Carnot engine.

It is basically a reference engine and is
 used for defining the thermodynamic temp scale.

$$C_V(T_H - T_L)$$

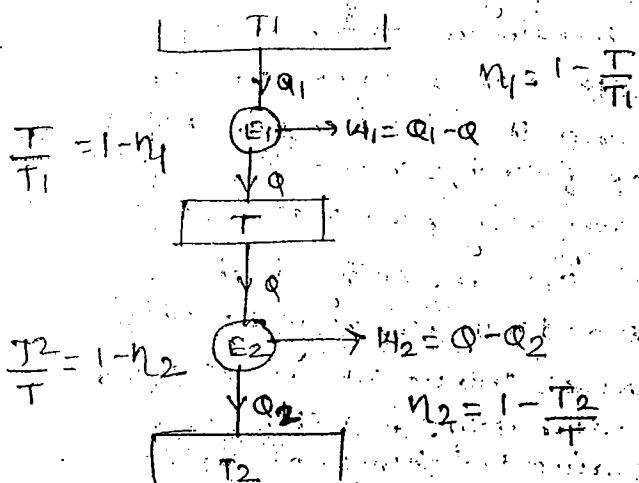
$$\eta = 1 - \frac{T_L}{T_H} \quad \left(\frac{d\eta}{dT_L} \right)_{T_H=C} = -\frac{1}{T_H} = -\frac{1}{T_H} \times \frac{T_H}{T_H} = -\frac{T_H}{T_H^2}$$

$$\left(\frac{d\eta}{dT_H} \right)_{T_L=C} = \frac{T_L}{(T_H)^2}$$

$$\left(\frac{d\eta}{dT_L} \right)_{T_H=C} > \left(\frac{d\eta}{dT_H} \right)_{T_L=C}$$

depend
 upon the

changing the sink temp has a greater improvement in η
 when compared to changing the source temp.



Equal work output

$$W_1 = W_2 \quad h \cdot F \propto \text{Temp}$$

$$Q_1 - Q_2 = Q - Q_2 \quad T = \frac{T_1 + T_2}{2}$$

$$Q = \frac{Q_1 + Q_2}{2}$$

For equal work output condition the intermediate temp is the arithmetic mean of remaining two temp.

$$\boxed{\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}}$$

Equal efficiency

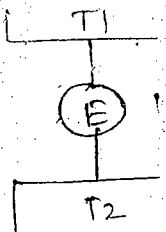
$$\eta_1 = \eta_2$$

$$1 - \frac{T}{T_1} = 1 - \frac{T_2}{T}$$

$$T = \sqrt{T_1 T_2}$$

For equal η condition, the intermediate temp is geometric mean of remaining temp.

$$\boxed{\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}}$$



overall e

$$\eta_1 = 50\%$$

$$\eta_0 = \eta_1 + \eta_2$$

η_0 of co

For n cyc

$$(1 - \eta_0)$$

Ind law

It's impo

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Kelvin and

an engine

"It is

only pure

reservoir

an engine

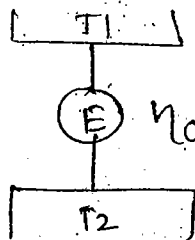
A device

called

State p

impossib

Overall efficiency



$$\eta_0 = 1 - \frac{T_2}{T_1} \quad \frac{T_2}{T_1} = 1 - \eta_0$$

$$\frac{T_2}{T_1} = \frac{T_2}{T} \times \frac{T}{T_1}$$

$$(1 - \eta_0) = (1 - \eta_1) \times (1 - \eta_2)$$

$$\boxed{\eta_0 = \eta_1 + \eta_2 - \eta_1 \eta_2}$$

Overall efficiency of coupled cycle

$$\eta_1 = 30\% \quad \eta_2 = 40\% \quad \eta_0 = ?$$

$$\eta_0 = \eta_1 + \eta_2 - \eta_1 \eta_2 = 0.3 + 0.4 - 0.3 \times 0.4 = 0.58$$

η_0 of coupled cycle is greater than the individual η

For n cycle:

$$(1 - \eta_0) = (1 - \eta_1)(1 - \eta_2) \dots (1 - \eta_n)$$

2nd law a qualitative law. It is a direction law.

It imposes a limitation on the amount of heat energy that can be converted to work.

Kelvin and plank have defined 2nd law with respect to an engine, which is called as 2nd law of thermodynamic

"It is impossible to construct an engine whose only purpose is absorb heat from a high temp reservoir and its conversion to work"

an engine with 100% is impossible.

A device which convert 100% heat to 100% work is

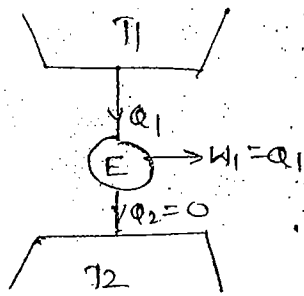
called perpetual motion of 2nd kind and 2nd law state perpetual motion machine 2nd kind (PMM2) is

impossible

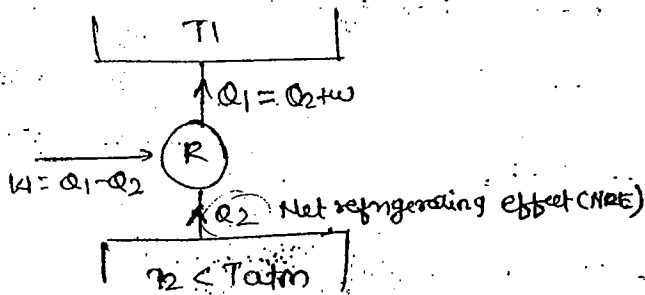
intermediate
ing two

temp is

If work is to be produced by an engine so amount of heat has to be rejected to a low temp reservoir unless you reject some heat you cannot do work.



Refrigerator: It is a device which maintains a temperature less than the atmospheric by continuously removing heat from a low temp reservoir and transferring it to a high temp reservoir by doing external work.



$$(C.O.P.)_{ref} = \frac{\text{Net refrigerating effect}}{\text{work}} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2} = \frac{T_2}{T_1 - T_2} \cdot \frac{T_1 - T_2}{T_1 - T_2} = \frac{T_2(T_1 - T_2)}{T_1 - T_2}$$

In C.O.P. improved

① whether source temp or sink temperature should be changed.

$$\left(\frac{dc}{dT_2}\right)_{T_1=C} = 1(T_1 - T_2)^{-1} + T_2(-1)(T_1 - T_2)^{-2}(-1) = \frac{1}{T_1 - T_2} + \frac{T_2}{(T_1 - T_2)^2} = \frac{T_1 - T_2 + T_2}{(T_1 - T_2)^2} = \frac{T_1}{(T_1 - T_2)^2}$$

$$C = 12 \text{ C.O.P.}$$

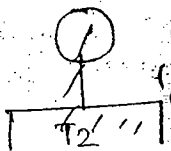
$$\left(\frac{dc}{dT_1}\right)_{T_2=C} =$$

$$\left(\frac{dc}{dT_2}\right)_{T_1=C}$$

changing P while C.O.P.

Coupled re

Q.C.O.



(C.O.P.)

(C.O.)

Equal w

$$W_1 =$$

$$Q_1 - Q_2 =$$

$$Q =$$

$$T =$$

of heat
reject

$$C = T_2 (T_1 - T_2)^{-1}$$

$$\left(\frac{dC}{dT}\right)_{T_2=C} = T_2 (-1) (T_1 - T_2)^{-2} (1) = \frac{-T_2}{(T_1 - T_2)^2}$$

$$\left(\frac{dC}{dT_2}\right)_{T_1=C} > \left(\frac{dC}{dT_1}\right)_{T_2=C}$$

Changing the T_{sink} has a great improvement in c.o.p.
while compare to change in T_{source} .

Coupled refrigerators

$$C.O.P._I = \frac{Q_1}{W_1} = \frac{Q_1}{Q_1 - Q_2}$$

$$\frac{T_1}{T_2} = 1 + \frac{1}{C.O.P._I}$$

$$C.O.P._I = \frac{T_2}{T_1 - T_2} \cdot \frac{Q_1}{Q_2} = 1 + \frac{1}{C.O.P._R} = \frac{1}{\frac{T_1}{T_2} - 1}$$

$$C.O.P._R = \frac{Q_2}{W_2} = \frac{T_2}{T_1 - T_2}$$

$$C.O.P._{overall} = \frac{T_2}{T_1 - T_2} = \frac{1}{\frac{T_1}{T_2} - 1}$$

$$\frac{T_1}{T_2} = 1 + \frac{1}{C.O.P._{over}}$$

Equal work input

$$W_1 = W_2$$

$$Q_1 - Q_2 = Q - Q_2$$

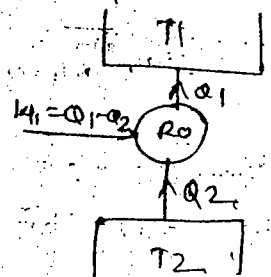
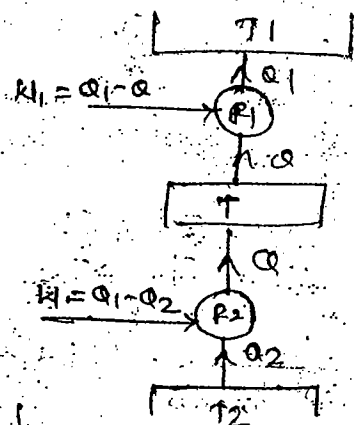
$$Q_1 - Q = Q - Q_2$$

$$Q = \frac{Q_1 + Q_2}{2}$$

$$T = \frac{T_1 + T_2}{2}$$

Intermediate temp is
the arithmetic mean of
remaining two temp.

$$\boxed{\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}}$$



$$1 - \frac{1}{c_1} = 1 - \frac{1}{c_2}$$

$$\frac{T_1}{T} = 1 + \frac{1}{c_1} \quad ; \quad \frac{T_2}{T} = 1 + \frac{1}{c_2}$$

$$\frac{T_1}{T} = \frac{T_2}{T} \quad T^2 = T_1 T_2 \quad T = \sqrt{T_1 T_2}$$

for equal coirp condition the intermediate temp is geometric mean of remaining two temperature

$$\boxed{\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}}$$

Overall C.O.P

$$\frac{T_1}{T_2} = \frac{T_1}{T} + \frac{T}{T_2}$$

$$1 + \frac{1}{(C.O.P)_{\text{overall}}} = \left(1 + \frac{1}{(C.O.P)_I}\right) + \left(1 + \frac{1}{(C.O.P)_II}\right)$$

$$\frac{1}{(C.O.P)_{\text{overall}}} = \frac{1}{(C.O.P)_I} + \frac{1}{(C.O.P)_II} + \frac{1}{(C.O.P)_I (C.O.P)_II}$$

If $(C.O.P)_I = 2$, $(C.O.P)_II = 3$ what is the $(C.O.P)_{\text{overall}}$ of coupled cycle

$$\frac{1}{C.O.} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_1 c_2}$$

$$= \frac{1}{2} + \frac{1}{3} + \frac{1}{2 \times 3} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = 1$$

$$(C.O.) = 1 \quad \boxed{C.O. < C_1} \quad \boxed{C.O. < C_2}$$

Clausius

"It is im device wh absorbs h temp resen to the high any exten

reservoir to

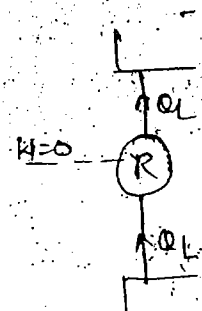
proof of statement

of false claim

of false claim

hence valid in all respo

185

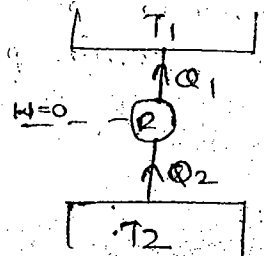


let the absorb de and reject and does pto truth

one const interaction the high to

Clausius Statement of 2nd Law of thermodynamics

"It is impossible to construct a device whose only purpose is to absorb the heat from low temp reservoir and its transfer to the high temp reservoir without any external work input"



If heat is to be transferred from a low temp reservoir to a high temp reservoir work should be done

Proof of equivalence of kelvin plank statement and clausius statement

① False clausius statement implies false kelvin plank statement

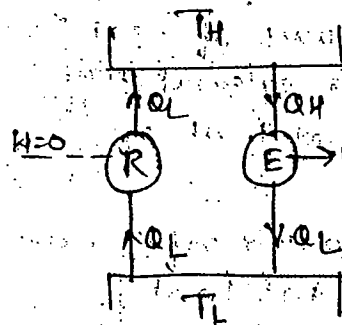
② False kelvin plank statement implies false clausius statement

hence 'kelvin plank' statement & 'clausius statement' are identical in all respect

1st

$\neg C \Rightarrow \neg K$

Let the engine operate both temp limit T_L & T_H which absorb Q_L amount of heat from the low temp reservoir and transverse it to high temp reservoir without any external work input



It is false refrigerator hence it is false of clausius statement

Let the engine operate in reverse direction which absorb Q_H amount of heat from high temp reservoir and reject Q_L amount of heat with low temp reservoir and does work $Q_H - Q_L$. hence it is a true engine and Pro truth of kelvin and plank statement

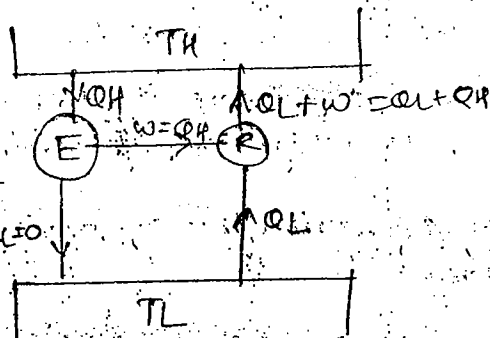
If both the engine and refrigerator together are considered as a self acting device the net heat interaction with the low temp reservoir is Zero and the high temp reservoir is $Q_H - Q_L$

and amount of workdone is $Q_H - Q_L$ $\therefore 100\%$ heat converted to 100% work hence it is a false engine and falsify of Kelvin plank statement

$$\therefore -C \Rightarrow -K$$

$$II) -K \Rightarrow -C$$

Let an engine operate betw the temp limit T_H and T_L which absorbs Q_H amount of heat from a high temp reservoir rejects Q_L amount of heat to the low temp reservoir and does work $W = Q_H - Q_L$ hence it is false engine and falsify of Kelvin plank statement



Let a refrigerator operate betw temp limit T_L and T_H which absorbs Q_L amount of heat from the low temp reservoir and transverse $Q_L + W$ amount of heat to the high temp reservoir by using an external work input hence it is a true refrigerator and truth of Clausius statement

If consider engine and refrigerator together as a self acting device the net heat interaction with high temp reservoir Q_L and with the low temp reservoir is also Q_L and Q_L amount of heat is transferred from low to high without any work input hence it is false refrigerator and falsify of Clausius statement and hence

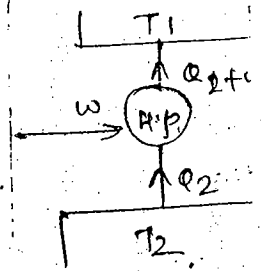
$$-K \Rightarrow -C$$

$$\therefore \text{hence } -K \Rightarrow -C, -C \Rightarrow -K$$

$$\therefore \boxed{K \Rightarrow C} \quad K \text{ is } \boxed{K \Leftrightarrow C}$$

Heat pump

heat pu of atmos and by doi



(C.O.P)

$\left[\frac{C}{C} \right]$

To impro whether

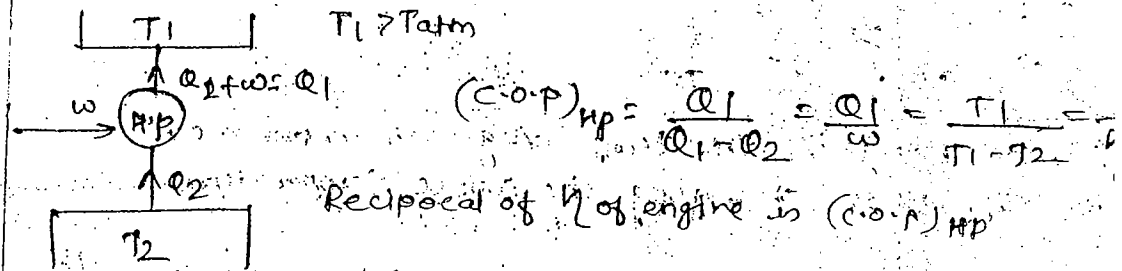
$$C = C.O.P = \frac{Q_L}{W}$$

$$\left(\frac{dC}{dT_L} \right)_{T_2=C}$$

... (100) heat engine and

Heat pump

heat pump is device which maintain a temp above T_1 of atmospheric ~~etc~~ by continuously supplying heat to and by doing external work



$$(C.O.P.)_{HP} = \frac{Q_1}{Q_1 - Q_2} = \frac{Q_1}{w} = \frac{T_1}{T_1 - T_2}$$

Reciprocal of η of engine is $(C.O.P.)_{HP}$

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

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

$$(C.O.P.)_{HP} = 1 + (C.O.P)_R = \frac{1}{\eta_E}$$

$$(C.O.P.)_R = \frac{1}{\eta_E} - 1 = \frac{1 - \eta_E}{\eta_E}$$

To improve the C.O.P of H.P what should be done whether we should change T_{source} or T_{sink}

$$C.O.P = \frac{T_1}{T_1 - T_2} = T_1 (T_1 - T_2)^{-1}$$

$$\left(\frac{dc}{dT_1} \right)_{T_2=C} = 1 (T_1 - T_2)^{-1} + T_1 (-1) (T_1 - T_2)^{-2} (1)$$

$$= \frac{1}{T_1 - T_2} - \frac{T_1}{(T_1 - T_2)^2}$$

$$= \frac{T_1 - T_2 - T_1}{T_1 - T_2} = \frac{-T_2}{(T_1 - T_2)^2}$$

Q.4
in plank

T_1 and T_2
as temp
if heat to
nal work
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refrigerator
heat
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amount
without any
mod

$$\left(\frac{dc}{dT_2}\right)_{T_1=C} = \frac{T_1(-1)(T_1-T_2)^2(-1)}{(T_1-T_2)^2} \quad (-ve \text{ sign indicates opp direction})$$

$$\left(\frac{dc}{dT_2}\right)_{T_1=C} > \left(\frac{dc}{dT_1}\right)_{T_2=C}$$

hence change in sink temp on greater improvement in cop than changing the source temperature

Coupled heat pump

$$(C.O.P)_I = \frac{T_1}{T_1 - T} = \frac{1}{1 - \frac{T}{T_1}}$$

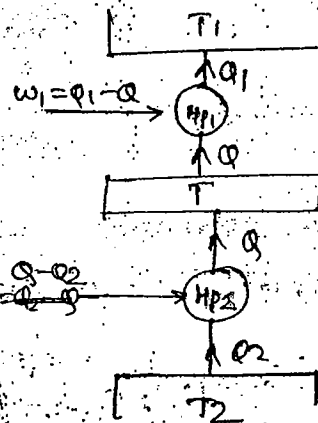
$$\frac{T}{T_1} = 1 - \frac{1}{C_1}$$

$$(C.O.P)_II = \frac{T}{T - T_2} = \frac{1}{1 - \frac{T_2}{T}}$$

$$\frac{T_2}{T} = 1 - \frac{1}{C_2}$$

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

$$(C.O.P)_{overall} = \frac{T_1}{T_1 - T_2} = \frac{1}{1 - \frac{T_2}{T_1}}$$



$$\boxed{\frac{T_2}{T_1} = 1 - \frac{1}{C.O.}}$$

Equal work input

$$W_1 = W_2$$

$$Q_1 - Q = Q - Q_2$$

$$Q = \frac{Q_1 + Q_2}{2}$$

$$T = \frac{T_1 + T_2}{2}$$

$$Q \propto T$$

Temp T_2

$$\boxed{\frac{Q_1}{T_1}}$$

Equal

$$\frac{T}{T_1}$$

Apply

$$\boxed{\frac{C}{T}}$$

for equi Geometri

$$(C.O.P)_O$$

if $Q =$
coupled

$$\frac{1}{C.O.}$$

$$C.O.$$

$$C.O.$$

For equal mass input condition the intermediate temp is arithmetic mean of remaining two temp

$$\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}$$

Equal c.o.p

$$\frac{T}{T_1} = 1 - \frac{1}{C_1} \quad \& \quad \frac{T_2}{T} = 1 - \frac{1}{C_2}$$

$$C_1 = C_2$$

$$\frac{T}{T_1} = \frac{T_2}{T}$$

$$T^2 = T_1 T_2$$

$$T = \sqrt{T_1 T_2}$$

Apply condition

$$\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}$$

For equal c.o.p the intermediate temp is the Geometric mean of remaining two temp.

(C.o.p) overall

$$\frac{T_2}{T_1} = \frac{T_2}{T} \times \frac{T}{T_1}$$

$$\left(1 - \frac{1}{C_0}\right) = \left(1 - \frac{1}{C_1}\right) \left(1 - \frac{1}{C_2}\right)$$

$$\frac{1}{C_0} = \frac{1}{C_1} + \frac{1}{C_2} - \frac{1}{C_1 C_2}$$

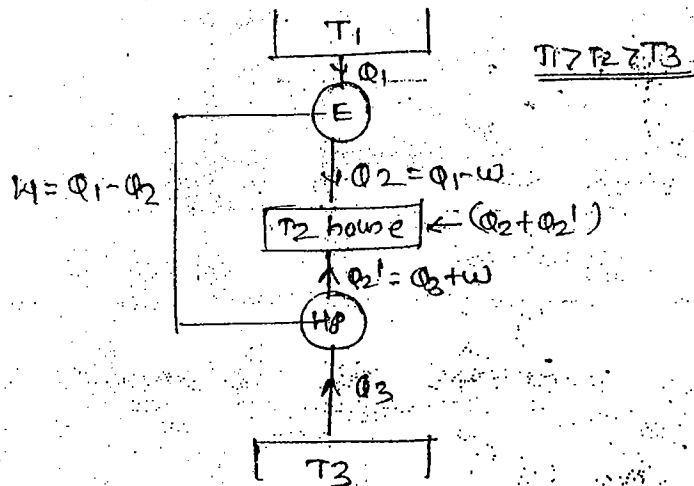
If $C_1 = 2$ $C_2 = 3$ what is (C.o.p) overall of coupled heat pump

$$\frac{1}{C_0} = \frac{1}{2} + \frac{1}{3} - \frac{1}{2 \times 3} = \frac{5}{6} - \frac{1}{6} = \frac{4}{6} = \frac{2}{3} \Rightarrow C_0 = \frac{3}{2} = 1.5$$

$$C_0 < C_1$$

$$C_0 < C_2$$

Lord Kelvin was the 1st person to suggest that a phenomenal large amount of heat can be supplied to a house by using very little energy as input. Hence this is done by using a engine & heat pump combination. This system are widely used in all cold countries for heating purposes. to save on fuel consumed



Multiplication factor = $\frac{\text{Heat Supplied to house}}{\text{Heat supplied to engine}}$

Multiplication factor = $\frac{Q_2 + Q_2'}{Q_1}$

$\eta_E = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$

$Q_2 = \frac{T_2}{T_1} Q_1$

$(C.O.P.)_{HP} = \frac{T_2}{T_2 - T_3} = \frac{T_2}{W} Q_2'$

$Q_2' = \frac{T_2}{T_2 - T_3} W$

$= \left(\frac{T_2}{T_2 - T_3} \right) (Q_1 - Q_2)$

$= \left(\frac{T_2}{T_2 - T_3} \right) \left(Q_1 - \frac{T_2}{T_1} Q_1 \right)$

$Q_2' = \frac{T_2}{T_1} Q_2$

$Q_2 + Q_2'$

* Multi

A large using c

$T_1 = 200$ factor

MF =

if MF is bur

Suppli and t

- A
to a house
is done by
system and
poses to

$$Q_2 = \left(\frac{T_2}{T_1} \right) \left(\frac{T_1 - T_2}{T_2 - T_3} \right) Q_1$$

$$\begin{aligned} Q_2 + Q_2' &= \frac{T_2}{T_1} Q_1 + \frac{T_2}{T_1} \left(\frac{T_1 - T_2}{T_2 - T_3} \right) Q_1 \\ &= \frac{T_2}{T_1} Q_1 \left[1 + \frac{T_1 - T_2}{T_2 - T_3} \right] \\ &= \frac{T_2}{T_1} Q_1 \left[\frac{T_1 - T_3}{T_2 - T_3} \right] \end{aligned}$$

* Multiplication factor $MF = \frac{Q_2 + Q_2'}{Q_1} = \frac{T_2}{T_1} \left[\frac{T_1 - T_3}{T_2 - T_3} \right]$

A large amount of heat supplied to house
using only little energy as heat input

house
engine

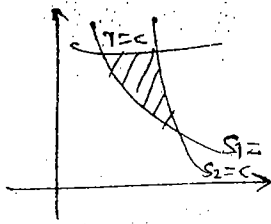
$T_1 = 200^\circ\text{C}$ $T_2 = 20^\circ\text{C}$ $T_3 = -10^\circ\text{C}$ the multiplication factor is

$$\begin{aligned} MF &= \frac{T_2}{T_1} \left[\frac{T_1 - T_3}{T_2 - T_3} \right] \\ &= \frac{20}{200} \left[\frac{200 - (-10)}{20 - (-10)} \right] \\ &= \underline{0.7} \cdot \frac{(20 + 273)}{(200 + 273)} \left[\frac{(200 + 273) - (-10 + 273)}{(20 + 273) - (-10 + 273)} \right] \\ &= \underline{4.33} \end{aligned}$$

if MF is 4.33 which tells that if 4 kJ of fuel
is burned with engine then 4.33 kJ can be
supplied to the house. this is the maximum possible
and the actual supply is less than this

ways, the assumption that two adiabatic lines intersect is wrong if not
 why not

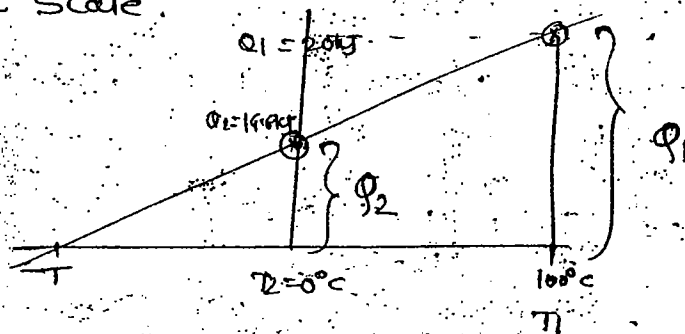
⇒ let assume path intersect



let them be connected by an isothermal line. the area under diagram represent work done and work is done only in heat is transfer only in the isothermal process and work is

produced by exchanging heat with only one thermal reservoir which is a violation of kelvin plank statement hence the assumption made two adiabatic intersect is false.

* 20 kJ heat is supplied at a temp have 100°C and 14.6 kJ heat is rejected at a temp of 0°C what is the absolute 0° temp on the thermodynamic scale.

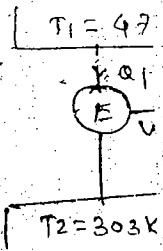


$$\frac{Q_1}{100+T} = \frac{Q_2}{0+T}$$

$$\frac{20}{100+T} = \frac{14.6}{T}$$

$$\boxed{T = -270.8^{\circ}\text{C}}$$

Figure 14



$$(COP)_R =$$

$$\frac{Q_3}{0.359 Q_1}$$

$$\left[\frac{Q_3}{Q_1} \right]$$

$$\frac{Q_3}{Q_1} = 3.68$$

$$C_d = 1880 \frac{\text{kg}}{\text{m}^2 \text{h}}$$

$$T_2 = 29$$

Cd = collection

Ar

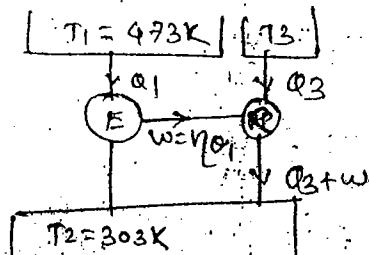
if not

isothermal

no
s done
in
work is
one
kelvin
e two

100°C
e 100°C
0°C

pg No 14. Q.3:



$$(C.O.P)_R = \frac{Q_3}{W} = \frac{T_3}{T_2 - T_3}$$

$$\frac{Q_3}{0.359 Q_1} = \frac{243}{303 - 243}$$

$$\frac{Q_3}{Q_1} = 1.45$$

$$\frac{Q_1}{Q_3} = ?$$

$$W_{\text{work}} = \eta Q_1$$

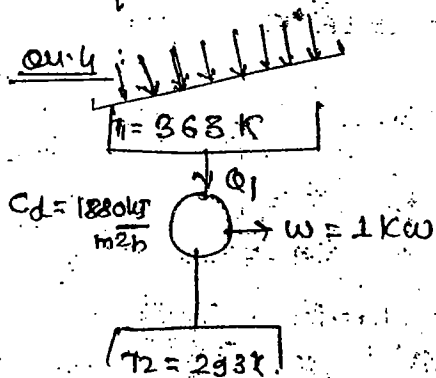
$$= \left(\frac{T_1 - T_2}{T_1} \right) Q_1$$

$$= \left(\frac{473 - 303}{473} \right) Q_1$$

$$W = 0.359 Q_1$$

$$\frac{Q_1}{Q_3} = \frac{1}{1.45} = 0.687$$

Q.4



C_d = collection density

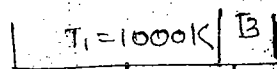
for minimum collector area a condition the work output is maximum and maximum work output for Carnot efficiency

$$\eta_c = \frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

$$\frac{1 \text{ kW}}{Q_1} = \frac{363 - 293}{363}$$

$$Q_1 = 5.1857 \text{ kW}$$

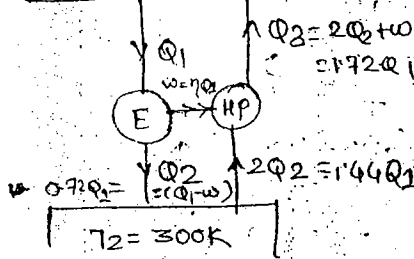
$$\text{Area} = \frac{Q_1}{C_d} = \frac{5.185 \text{ kW}}{\frac{1880 \text{ W}}{3600 \text{ h}}} = 9.93 \text{ m}^2$$



$$\eta_E = \frac{T_1 - T_2}{T_1} = \frac{W}{Q_1}$$

$$\frac{1000 - 300}{1000} = \frac{W}{Q_1}$$

$$W = 0.7 Q_1$$



$$W_{actual} = 0.4 \times 0.7 Q_1 = 0.28 Q_1$$

$$(C.O.P.)_{HP} = \frac{Q_3}{W} = \left(\frac{T_3}{T_3 - T_2} \right) 0.5$$

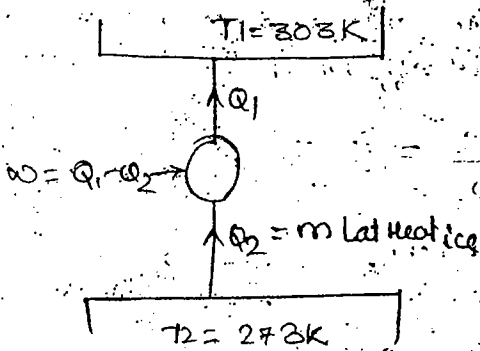
$$\frac{1.72 Q_1}{0.28 Q_1} = 0.5 \left[\frac{T_3}{T_3 - 300} \right]$$

$$T_3 = 326^\circ K$$

$$Q_3 = 1.72 Q_1 = 1.72 \times 50 = 86 \text{ kW}$$

Monthly

Q4.9:



$$(C.O.P.)_R = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

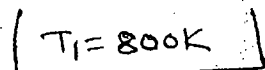
$$= \frac{\text{mass. Lat. ice}}{W} = \frac{T_2}{T_1 - T_2}$$

$$= \frac{1000 \times 335}{W} = \frac{273}{303 - 273}$$

$$W = 36,813 \text{ kJ}$$

$$1 \text{ kW/hr} = 3600 \text{ kJ}$$

$$\text{Electrical work} = \frac{36,813}{3600} = 10.22 \text{ kW hr}$$



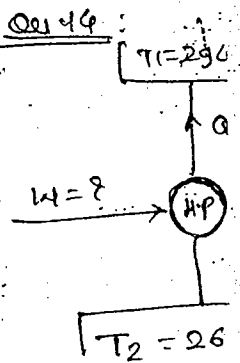
$$Q_1 = 1000 \text{ kJ}$$

$$W_c = \eta Q_1 = \left(\frac{T_1 - T_2}{T_1} \right) Q_1$$

$$= \left(\frac{800 - 400}{800} \right) 1000 = 500$$

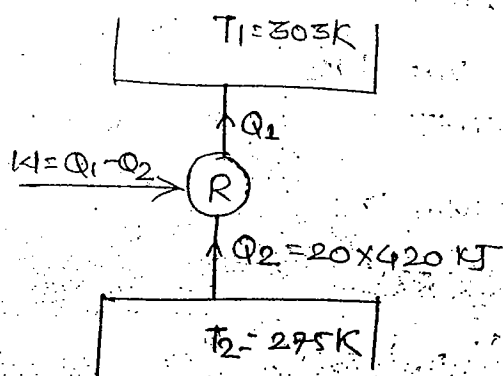
$W_{act} > W_{carnot}$ hence claim is not justified

Q4.13:



with HP with elect running co

Q1.10



$$(\text{C.O.P.})_{\text{actual}} = 0.15 (\text{C.O.P.})_{\text{max}}$$

$$= 0.15 \times \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W}$$

$$= 0.15 \times \frac{295}{303 - 295} = \frac{20 \times 42}{W}$$

$$W = 5701.15 \text{ kJ/hr}$$

$$1 \text{ kWhr} = 3600 \text{ kJ}$$

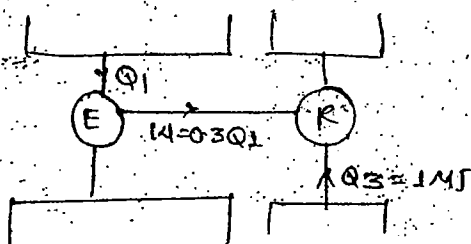
$$= \frac{5701.15}{3600} = 1.58 \text{ kWhr/d}$$

$$\text{Monthly bill} = \frac{\text{No. of unit/day}}{\text{unit/day}} \times \text{No. of days} \times \frac{\text{cost}}{\text{unit}}$$

$$= 1.58 \times 30 \times 0.32$$

$$= \underline{\underline{15.168 \text{ /-}}}$$

Q1.13

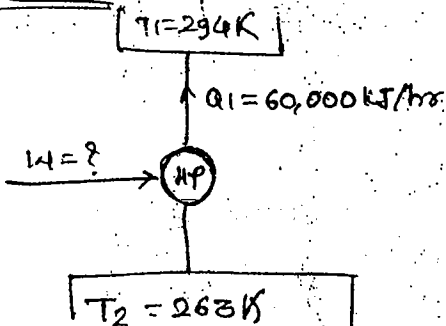


$$(\text{C.O.P.})_R = 5 = \frac{Q_3}{W}$$

$$W = 5 = \frac{1 \text{ MJ}}{0.3 Q_1}$$

$$Q_1 = 0.67 \text{ MJ}$$

Q1.14



$$(\text{C.O.P.})_{\text{HP}} = \frac{Q_1}{W} = \frac{T_1}{T_1 - T_2}$$

$$= \frac{60,000}{W} = \frac{294}{294 - 263}$$

$$W = 6326.53 \text{ kJ/hr}$$

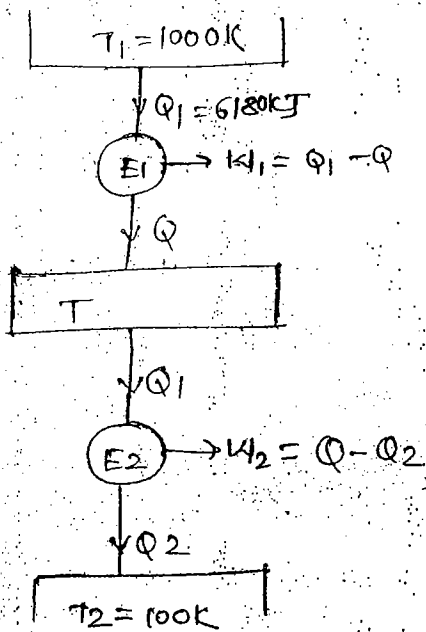
$$\frac{W_{\text{HP}}}{W_{\text{EH}}} = \frac{6326.53}{60,000}$$

$$= \underline{\underline{0.1054}}$$

With H.P initial investment is high but running cost is less with electrical heater. the initial investment is less but running cost is high.

justified

Q1.16:



Equal works

$$W_1 = W_2$$

$$T = \frac{T_1 + T_2}{2}$$

$$= \frac{1000 + 100}{2}$$

$$= 550 \text{ K}$$

$$\frac{Q_1}{T_1} = \frac{Q}{T} = \frac{Q_2}{T_2}$$

$$\frac{6180}{1000} = \frac{Q}{550} = \frac{Q_2}{100}$$

$$Q = 924, Q_2 = 168$$

$$\eta_1 = \frac{T_1 - T}{T_1} = \frac{1000 - 550}{1000} = 0.45$$

$$\eta_2 = \frac{T - T_2}{T} = \frac{550 - 100}{550} = 0.818$$

equal efficiency

$$\eta_1 = \eta_2$$

$$T = \sqrt{T_1 T_2} = \sqrt{1000 \times 100} = 316.2 \text{ K}$$

$$\eta_1 = \frac{T_1 - T}{T_1} = \frac{W_1}{Q_1}$$

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2} = \frac{Q}{T}$$

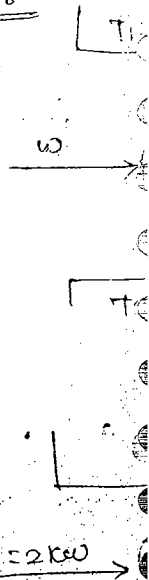
$$Q_1 \frac{6180}{1000} = \frac{Q_2}{100} = \frac{9240}{316.2}$$

$$Q_2 = 168$$

$$W_1 = Q_1 - Q$$

$$W_2 = Q - Q_2$$

Q1.18



$$0.65(T_1 - T_2)$$

(COP)

Q1.20

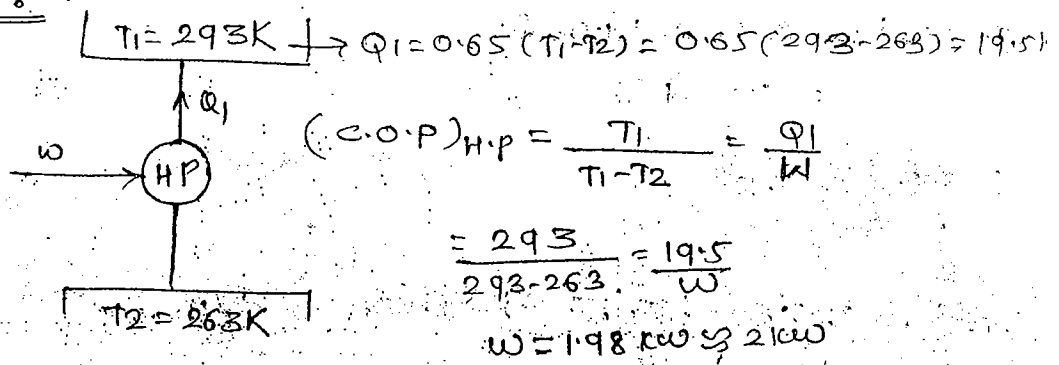
$$\eta_E = 0.27$$

$$(\text{COP})_P = 4$$

$$W = 2.5 \text{ kW}$$

$$= 0.27 \text{ kW}$$

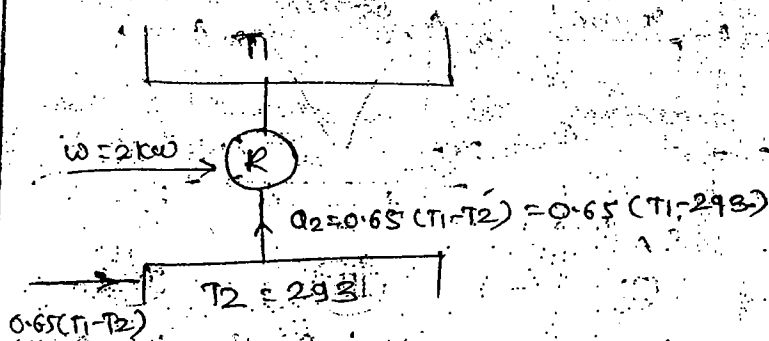
Qu. 18



Qu. 19

100

8



$$(\text{C.O.P.})_R = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

$$\frac{0.65(T_1 - 293)}{2} = \frac{293}{T_1 - 293}$$

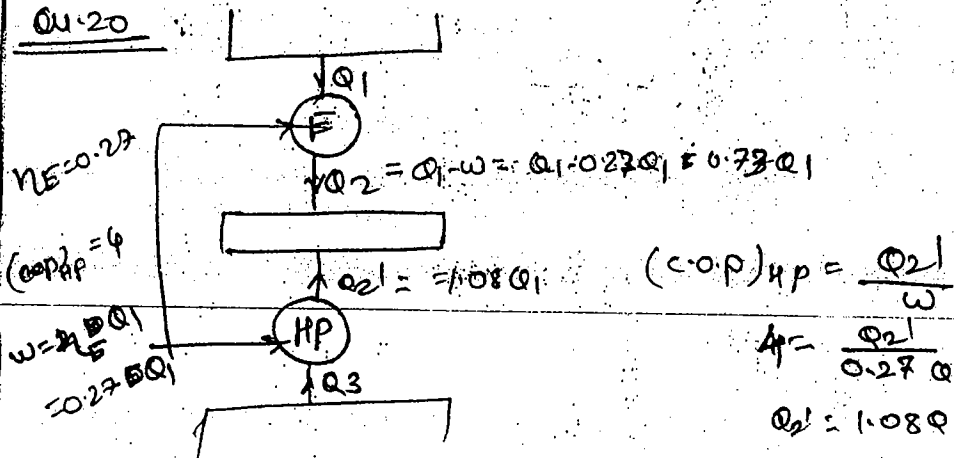
$$\frac{0.65T_1 - 190.45}{2} = \frac{293}{T_1 - 293}$$

$$\frac{0.65T_1}{2} = \frac{293}{T_1 - 293} + 190.45$$

$$0.65T_1(T_1 - 293) = 293 \times 2 + 190.45$$

$$T_1 = 323 \text{ K}$$

Qu. 20

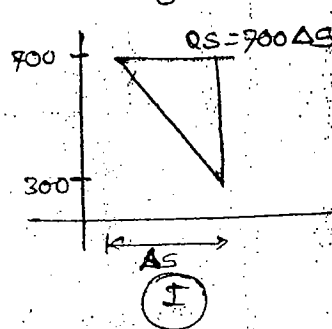


$$Q_2 + Q_2' = 0.73 Q_1 + 1.08 Q_1$$

$$= 1.81 Q_1$$

$$\frac{Q_2 + Q_2'}{Q_1} = 1.81$$

which engine having the highest η_{thermal} among the four

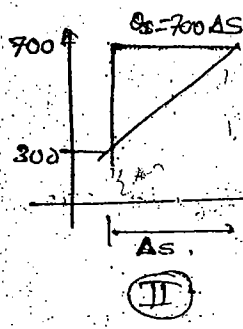


$$W = \frac{1}{2} \times \Delta S \times 400$$

$$Q_s = 700 \Delta S$$

$$\eta_I = \frac{2}{3}$$

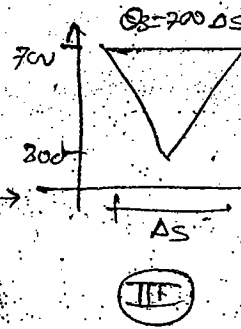
$$\boxed{\eta_{\text{max}} = 4/5}$$



$$W = \frac{1}{2} \Delta S \times 400$$

$$Q_s = 700 \Delta S$$

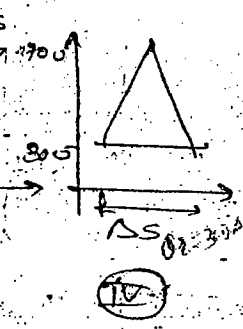
$$\eta_{II} = \frac{2}{3}$$



$$W = \frac{1}{2} \times \Delta S \times 400$$

$$Q_s = 700 \Delta S$$

$$\eta_{III} = \frac{2}{3}$$



$$W = \frac{1}{2} \Delta S \times 400$$

$$Q_s = 800 \Delta S$$

$$Q_s = Q_r + W$$

$$= 500 \Delta S$$

$$\eta = \frac{200}{500}$$

$$= 0.4$$

η_{Carnot}

η_{actual}

η_{Carnot}

(C)

Q. No. 12 Q. 2

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{72}{T_1}$$

$$\frac{Q_2}{Q_1} = \frac{72}{T_1}$$

$$\frac{Q_2}{40} = \frac{200}{1200}$$

$$\boxed{Q_2 = 10 \text{ kW}}$$

Q. 6

$$Q_2 + 0.6 Q_1 +$$

650
220
1000

Ques 3

$$Q_S = 36 \times 10^8 \text{ kJ/hr}$$

$$= \frac{36 \times 10^8}{3600 \times 10^3} \text{ MW}$$

$$= 1000 \text{ MW}$$

$$Q_R = Q_S - W$$

$$= 1000 - 400 = 600 \text{ MW}$$

errata

Ques 4

power = 50 kW

$$Q_S = \dot{m} \dot{h} \times c_v$$

$$\downarrow$$

$$\text{kg/sec} \times \text{kJ/kg}$$

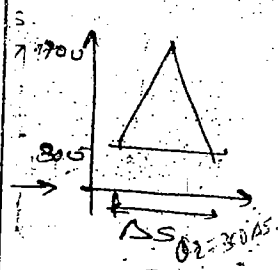
$$= \frac{2 \times 75000}{3600}$$

$$\eta = \frac{50}{\frac{2 \times 75000}{3600}} = 0.8$$

$$\eta_{\text{Carnot}} = \frac{T_1 - T_2}{T_1}$$

$$= \frac{627 - 27}{(627 + 273)} = \frac{600}{900} = 67\%$$

$\eta_{\text{actual}} > \eta_{\text{Carnot}}$ hence engine is not possible



100

$$W = \frac{1}{2} \Delta S \times 400$$

$$Q_S = 300 \Delta S$$

$$Q_S = Q_R + W$$

$$= 500 \Delta S$$

$$\eta = \frac{200}{500}$$

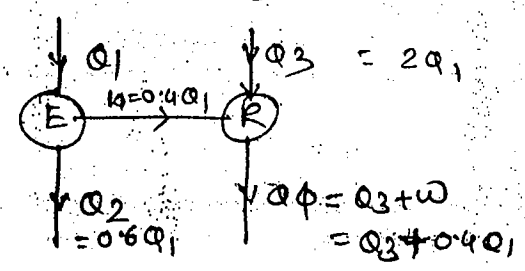
$$= 0.4$$

Ques 5 $\eta_{\text{Carnot}} = 0.75$ (C.O.P)_{ref} = ?

$$(C.O.P)_{\text{ref}} = \frac{1 - \eta_E}{\eta_E}$$

$$= \frac{1 - 0.75}{0.75} = \frac{1}{3} = 0.33$$

Ques 6



$$Q_2 + Q_4 = 3Q_1$$

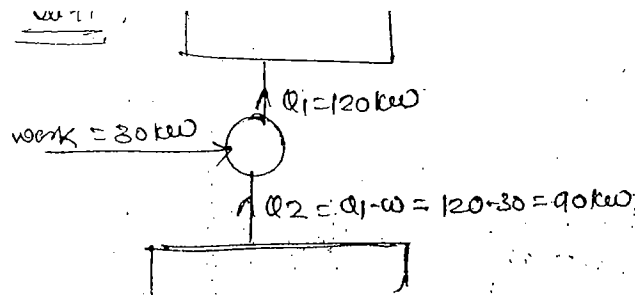
$$0.6Q_1 + Q_3 + 0.4Q_1 = 3Q_1$$

$$Q_3 = 2Q_1$$

$$(C.O.P)_R = \frac{Q_3}{W}$$

$$= \frac{2Q_1}{0.4Q_1}$$

$$= 5$$



$$(C.O.P)_R = \frac{Q_2}{W} = \frac{90}{30} = 3$$

Ques 17

$$\eta_1 = \frac{W}{Q_1} = \frac{8.2}{\frac{1500}{60}} = 0.328$$

$$\eta_2 = \frac{2.75}{\frac{1600}{60}} = 0.328$$

$$\eta_3 = \frac{9.3}{\frac{1700}{60}} = 0.328$$

$$\eta_4 = \frac{9.85}{\frac{1800}{60}} = 0.328$$

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

$$0.328 = \frac{W}{\frac{2000}{60}}$$

$$W = 1095 \text{ J}$$

Q. 20 :-

ENI

CLASS

2nd cycle
than or

$$\oint$$

$$\oint \frac{dQ}{T}$$

$$\oint \frac{dQ}{T}$$

$$\oint \frac{dQ}{T}$$

Reversible

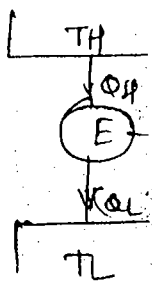
$$\int$$

$$\oint \frac{dQ}{T}$$

For rev.

clausius

Invers



ENTROPY

CLAUSIUS INEQUALITY

In cycle process heat transfer to the temp is less than or equal to zero.

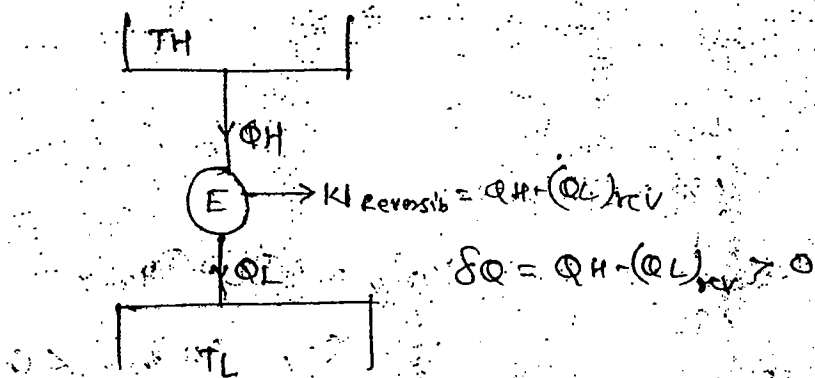
$$\oint \frac{dQ}{T} \leq 0$$

$$\oint \frac{dQ}{T} = 0 \text{ Reversible cycle}$$

$$\oint \frac{dQ}{T} < 0 \text{ irreversible cycle}$$

$$\oint \frac{dQ}{T} > 0 \text{ impossible cycle (violate the 2nd law)}$$

Reversible engine (no losses) (Carnot cycle)

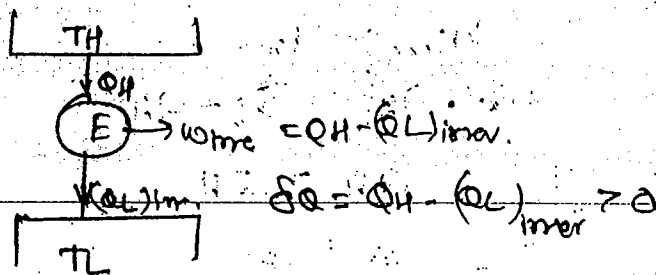


$$\oint \frac{dQ}{T} = \frac{Q_H}{T_H} - \frac{(Q_L)_{\text{rev}}}{T_L} = 0$$

For reversible engine $dQ > 0$ and $\oint \frac{dQ}{T} = 0$

Clausius inequality is proved for reversible engine.

Irreversible engine



irreversible engine work < reversible work
 irreversible work < reversible work

$$(W)_{irr} < (W)_{rev}$$

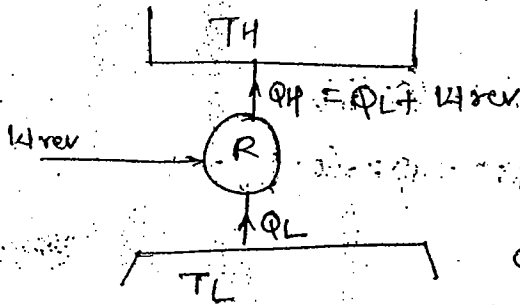
$$(Q_H) - (Q_L)_{irr} < (Q_H) - (Q_L)_{rev}$$

$$(Q_L)_{irr} > (Q_L)_{rev}$$

$$\oint \frac{dQ}{T} = \frac{Q_H}{T_H} - \frac{(Q_L)_{irr}}{T_L} < 0$$

Clausius Inequality is proved for a reversible and irreversible engine

Refrigerator

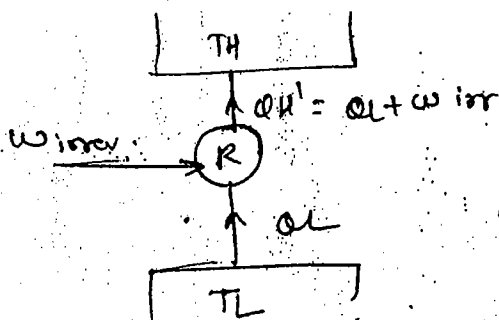


$$K_{rev} = \frac{Q_L}{Q_H - Q_L}$$

$$\oint dQ = Q_L - (Q_H)_{rev} < 0$$

$$\oint \frac{dQ}{T} = -\frac{(Q_H)_{rev}}{T_H} + \frac{Q_L}{T_L} = 0$$

Irreversible refrigerator



$$\oint dQ = Q_L - Q_H' < 0$$

$$W_{irr} > W_{rev}$$

$$Q_L + Q_H' > Q_L + Q_H$$

$$Q_H' > Q_H$$

$$\oint \frac{dQ}{T} = -\frac{Q_H'}{T_H} + \frac{Q_L}{T_L} < 0$$

$\oint \frac{dQ}{T}$ is d
 for a irre
 entropy d

$$(ds)_{iso}$$

$$(ds)_{isc}$$

$$dQ =$$

$$h = u$$

$$\frac{dh}{d} =$$

$$dh =$$

$$dQ =$$

$$TdS =$$

$$sc$$

$$ds =$$

$$\int_1^2 ds =$$

$$(S_2 - S_1)$$

for Irreversible Refrigerator $dQ < 0$, and $\oint \frac{dQ}{T}$ is also < 0 hence Clausius inequality is proved for a irreversible refrigerator.

$$\text{entropy change } \Delta S \geq \frac{dQ}{T}$$

$$(S_2 - S_1) \geq \frac{dQ}{T}$$

$(ds)_{\text{isolated}} \geq 0$ (irreversible isolated system)

$(ds)_{\text{isolated}} = 0$ is called reversible isolated system

$$dQ = du + dw = du + p dv$$

$$h = u + pv$$

$$\frac{dh}{d} = du + p dv + v dp$$

$$dh = dQ + v dp$$

$$dQ = dh - v dp$$

$$T ds = du + p dv$$

$$c_v dT + p dv$$

$$ds = \frac{c_v dT}{T} + \frac{p}{T} dv$$

$$= c_v \frac{dT}{T} + \frac{R}{V} dv$$

$$\int_1^2 ds = \int_1^2 c_v \frac{dT}{T} + \int_1^2 \frac{R}{V} dv$$

$$(S_2 - S_1) = c_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}$$

change in entropy when Temp & volⁿ change

$$= c_v \ln \frac{T_2}{T_1} + (c_p - c_v) \ln \frac{V_2}{V_1}$$

$$= c_v \ln \frac{T_2 V_1}{T_1 V_2} + c_p \ln \frac{V_2}{V_1}$$

$$(S_2 - S_1) = C_V \ln \frac{P_2}{P_1} + C_P \ln \frac{V_2}{V_1}$$

$$\boxed{\frac{S_2 - S_1}{C_V} = \ln \frac{P_2}{P_1} + \gamma \ln \frac{V_2}{V_1}}$$

$$dQ = dh - v dp$$

$$T ds = c_p dT - v dp$$

$$ds = \frac{c_p dT}{T} - \frac{v}{T} dp$$

$$= \int_1^2 c_p \frac{dT}{T} - \int_1^2 \frac{R}{P} dp$$

$$\boxed{S_2 - S_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}}$$

$$\frac{S_2 - S_1}{C_p} = \ln \frac{T_2}{T_1} - \frac{R}{C_p} \ln \frac{P_2}{P_1}$$

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

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

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

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

let us add this to specific process.

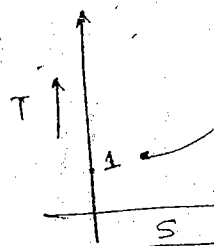
$$T ds = c_v dT + P dv$$

$V = C$ (isochoric or isometric)

$$dv = 0$$

$$T ds = c_v dT$$

$$\left(\frac{dT}{ds} \right)_v$$



$$\int_1^2 ds =$$

$$* T ds =$$

$$P =$$

$$T ds =$$

$$\frac{dT}{ds} = \frac{1}{c}$$

$$\left(\frac{dT}{ds} \right)_{P=C}$$

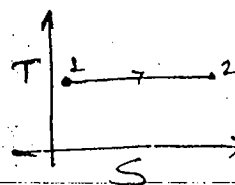
$$C_p > C_v$$

$$\left(\frac{dT}{ds} \right)_{P=C}$$

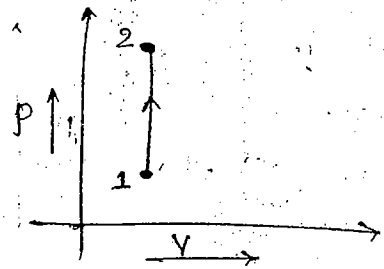
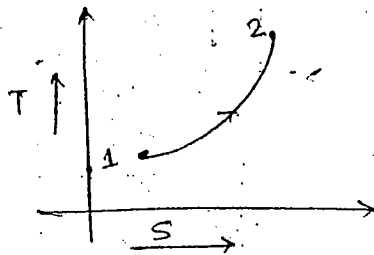
$$* T =$$

$$dQ =$$

$$\therefore ds$$



$$\left(\frac{dT}{ds}\right)_{v=c} = \frac{T}{C_v}$$



$$\int_1^2 ds = \int_1^2 C_v \frac{dT}{T}$$

$$(s_2 - s_1) = C_v \ln \frac{T_2}{T_1}$$

$$* \quad T ds = C_p dT - v dp$$

$$p = C \quad \therefore \boxed{dp = 0}$$

constant pressure or isobar

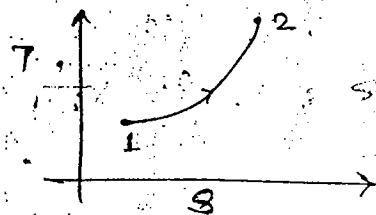
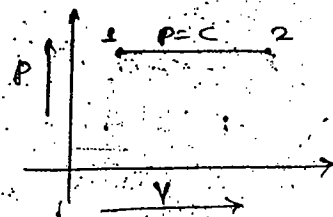
$$T ds = C_p dT$$

$$\frac{dT}{ds} = \frac{T}{C_p}$$

$$\left(\frac{dT}{ds}\right)_{p=c} = \frac{T}{C_p}$$

$$C_p > C_v$$

$$\left(\frac{dT}{ds}\right)_{p=c} < \left(\frac{dT}{ds}\right)_{v=c}$$

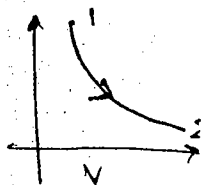


$$s_2 - s_1 = C_p \ln \frac{T_2}{T_1}$$

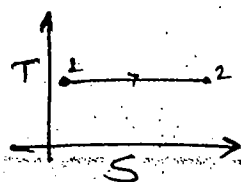
$$* \quad T = C \quad \text{Isothermal / constant Temp.}$$

$$dq = dw = p v_1 \ln \frac{v_2}{v_1} = p v_1 \ln \frac{p_1}{p_2}$$

$$= m R T_1 \ln \frac{v_2}{v_1} = m R T_1 \ln \frac{p_1}{p_2}$$



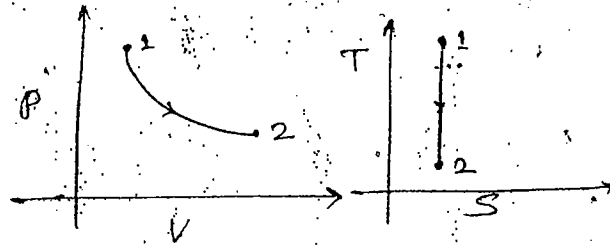
$$\therefore ds = \frac{dq}{T} = \frac{m R T_1 \ln \frac{v_2}{v_1}}{T_1} = \frac{m R T_2 \ln \frac{p_1}{p_2}}{T_2}$$



$$= m R \ln \frac{v_2}{v_1} = m R \ln \frac{p_1}{p_2}$$

Adiabatic process

$$dq = 0$$
$$ds = \frac{dq}{T} = 0$$



polytropic process

$$pv^n = c$$
$$TV^{n-1} = c$$
$$Tp^{\frac{1-n}{n}} = c$$

$$= \frac{n-1}{n} \times \text{workdone}$$

$$S_2 - S_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

$$T_1 v_1^{n-1} = T_2 v_2^{n-1}$$

$$\left(\frac{v_2}{v_1}\right)^{n-1} = \frac{T_1}{T_2}$$

$$\frac{v_2}{v_1} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}}$$

$$\frac{v_2}{v_1} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{1-n}}$$

$$S_2 - S_1 = C_v \ln \frac{T_2}{T_1} + R \ln \left(\frac{T_2}{T_1}\right)^{\frac{1}{1-n}}$$

$$= \frac{R}{\gamma-1} \ln \left(\frac{T_2}{T_1}\right) + \frac{R}{1-n} \ln \left(\frac{T_2}{T_1}\right)$$

$$= R \ln \frac{T_2}{T_1} \left[\frac{1}{\gamma-1} + \frac{1}{1-n} \right]$$

$$= R \ln \frac{T_2}{T_1} \left[\frac{1-n+\gamma-1}{(\gamma-1)(1-n)} \right]$$

$$\boxed{S_2 - S_1 = \frac{\gamma-n}{(\gamma-1)(1-n)} R \ln \frac{T_2}{T_1}}$$

$$\frac{T_2}{T_1} = \left(\frac{S_2 - S_1}{\frac{R}{1-n}} \right)^{\frac{1-n}{\gamma-n}}$$

$$S_2 - S_1 = \left(\frac{T_2}{T_1} \right)^{\frac{1-n}{\gamma-n}} \frac{R}{1-n}$$

$$\boxed{S_2 - S_1 = \frac{R}{1-n} \ln \frac{T_2}{T_1}}$$

$$S_2 - S_1 = \frac{R}{1-n} \ln \frac{T_2}{T_1}$$

on a p-v
under the
thermodynamic
workdone

or
under the

cycle the

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{\gamma-n}$$

$$S_2 - S_1 = \frac{(\gamma-n) R}{(\gamma-1)(1-n)} \ln \left(\frac{V_2}{V_1}\right)^{\gamma-n}$$

$$\boxed{S_2 - S_1 = R \left(\frac{\gamma-n}{\gamma-1}\right) \ln \frac{V_2}{V_1}}$$

$$\neq P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\left(\frac{V_2}{V_1}\right)^\gamma = \frac{P_1}{P_2}$$

$$\boxed{\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/\gamma} = \left(\frac{P_2}{P_1}\right)^{-1/\gamma}}$$

$$S_2 - S_1 = R \frac{(\gamma-n)}{(\gamma-1)} \ln \left(\frac{P_2}{P_1}\right)^{-1/\gamma}$$

$$= -\frac{R}{n} \frac{(\gamma-n)}{(\gamma-1)} \ln \frac{P_2}{P_1}$$

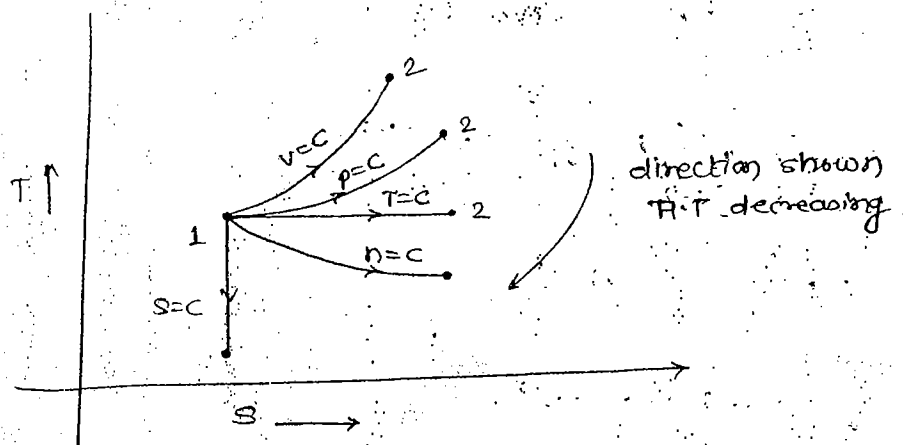
$$\boxed{S_2 - S_1 = \frac{R}{n} \left(\frac{n-\gamma}{\gamma-1}\right) \ln \frac{P_2}{P_1}}$$

on a $p-v$ diagram for a process the area under the curve gives workdone and for thermodynamic cycle the area enclosed gives the workdone.

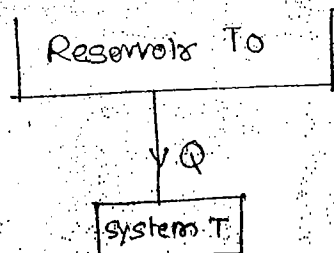
on $T-S$ diagram for a process the area under the curve gives the heat supplied.

For a $T-S$ diagram for thermodynamic cycle the area enclosed gives the workdone.

t₁t₂



Consider the side their on other side further T fluid mixed heat lost $m c_p (t_1 - t_2)$



$$(ds)_{\text{system}} = + \frac{Q}{T}$$

$$(ds)_{\text{Reservoir}} = - \frac{Q}{T_0} \quad T_0 > T$$

$$(ds)_{\text{universe}} = Q \left[\frac{1}{T} - \frac{1}{T_0} \right]$$

$$(ds)_{\text{universe}} > 0 \quad \text{irreversible in nature}$$

$$(ds)_{\text{universe}} = 0 \quad \text{reversible in nature}$$

$$(ds)_{\text{universe}} < 0 \quad \text{violate the IInd law of thermodynamics}$$

For a process the entropy change can be the ve or or zero

if system and surrounding are considered the entropy change is only the or zero

$$t_f =$$

$$t_f =$$

IInd law

$$ds_1 =$$

$$ds_2 =$$

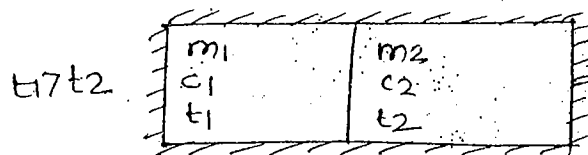
$$(ds)_{\text{sys}}$$

$$(ds)_{\text{surround}}$$

$$(ds)_{\text{universe}}$$

$$(ds)_{\text{universe}}$$

Adiabatic mixing of two fluids



Consider insulated vessel divided into two part on one side there is mass m_1 , specific heat c_1 and temp T_1 on other side it is mass m_2 , specific heat c_2 and temp T_2 further $T_1 > T_2$. let the membrane be ruptured two fluid mixed to get final temp T_f . using 1st law
heat lost = heat gained

$$m_1 c_1 (T_1 - T_f) = m_2 c_2 (T_f - T_2)$$

$$T_f = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{m_1 c_1 + m_2 c_2}$$

$$\begin{aligned} m_1 &= m_2 = m \\ c_1 &= c_2 = c \\ T_f &= \frac{T_1 + T_2}{2} \end{aligned}$$

IInd law apply

$$ds_1 = m_1 c_1 \ln \frac{T_f}{T_1}$$

$$ds_2 = m_2 c_2 \ln \frac{T_f}{T_2}$$

$$(ds)_{\text{system}} = ds_1 + ds_2 = m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2}$$

$$(ds)_{\text{surrounding}} = 0$$

$$(ds)_{\text{universe}} = (ds)_{\text{system}}$$

$$(ds)_{\text{universe}} = m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2}$$

$$m_1 = m_2 = m$$

$$Q_1 = Q_2 = C$$

$$= mc \ln \frac{t_f^2}{t_1 t_2}$$

$$= 2mc \ln \frac{t_f}{\sqrt{t_1 t_2}} = 2mc \ln \frac{t_1 + t_2}{2\sqrt{t_1 t_2}}$$

$$\left(\frac{t_1 + t_2}{2} \right) > \sqrt{t_1 t_2}$$

Arithmetic mean > Geometric mean

Answer > 0 hence it is irreversible process

For polytropic process heat rejected given by formula

$$Q_R = C_V \frac{r-n}{1-n} dT$$

$$C_V \frac{r-n}{1-n} = C_n dT$$

$$Q_R = C_n dT$$

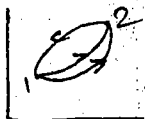
C_n = polytropic specific heat

Expansion

Compression process

Expansion		Compression process	
$1 < n < \gamma$	$n > \gamma$	$1 < n < \gamma$	$n > \gamma$
C_n (-ve)	C_n (+ve)	C_n is -ve	C_n is (+ve)
dT is (-ve)	dT (-ve)	dT (+ve)	dT (+ve)
Q is +ve	Q_R is -ve	Q_R (-ve)	Q_R (+ve)

In expansion process or in a compression process heat transfer can be +ve or -ve for a polytropic process.. depending on the value of 'n'



Entropy is point function. It depends only on end state and that it is independent of path followed. Hence it is an exact differential.

Sum of the entropy

Entropy and become equilibrium

Separated parameter which max when $\frac{ds}{dx}$ which is 0 when the entropy is

All adiabatic isentropic reversible

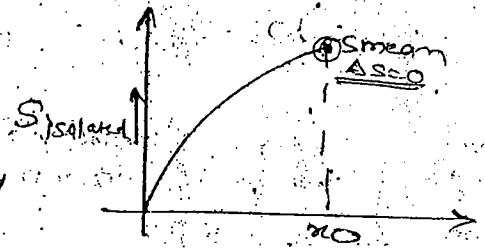
expansion



Entropy
~~Some~~ ^{sum} ~~total~~ ^{total} energy in universe is remain constant
the entropy of universe tends to maximise itself

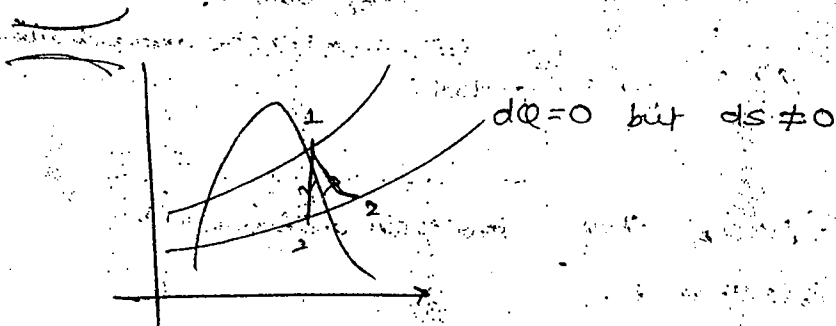
Entropy of an isolated system always increases and becomes a maximum at the state of equilibrium

Separated variables with parameter x , there is x_0 which maximise the entropy when $\frac{ds}{dx} = 0$

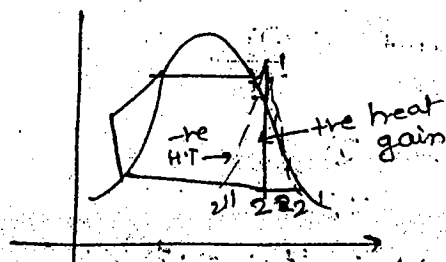


which is called as the state of equilibrium when the system is at the peak of entropy hill entropy considerable change in entropy would be zero.

All adiabatic processes are not isentropic, all isentropic processes are not adiabatic. only reversible adiabatic process is called as isentropic



expansion of steam in steam turbine



$dQ \neq 0$
 $ds = 0$

exp is turbine is isentropic not adiabatic

Entropy of a system is given by

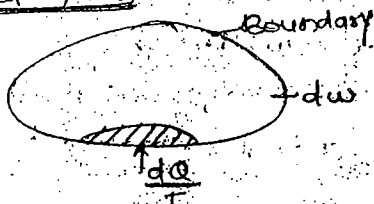
- ① by heat interaction in which there is entropy of transfer.
- ② by internal irreversibilities or dissipate the effect in which work is dissipated into increase in internal energy.

$$ds \geq \frac{dq}{T} \quad \therefore (S_2 - S_1) \geq \frac{dq}{T}$$

$$(S_2 - S_1) - \int \frac{dq}{T} = S_{gen} = S_{production}$$

↑ entropy change ↓ entropy transfer = entropy of generation

Closed system:



First law:

$$dq - dw = du$$

$$(S_2 - S_1) \geq \int \frac{dq}{T}$$

$$S_2 - S_1 - \int \frac{dq}{T} = S_{gen} = S_{production}$$

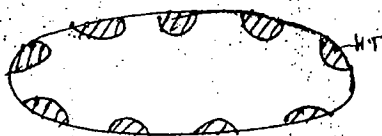
Any thermodynamic process is accompanied by S_{gen} or S_{prod} . If entropy of generation is zero, it is called a reversible process.

$S_{gen} > 0$ is called an irreversible process.

S_{gen} quantities

Intrinsic irreversibilities

$(S_{gen})_A > (S_{gen})_B$ then process A is said to be more irreversible than B.



$$S_2 - S_1 = S_{gen} + \sum \frac{Q_j}{T_j}$$

$$\frac{ds}{dt} = S_{gen} + \sum \frac{\dot{Q}_j}{T_j}$$

Heat transfer to a system increases the entropy and heat transfer from a system decreases the entropy the

lost con
with wo
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Entropy of

me

$$\sum m_i$$

$$\sum m_i$$

$$\sum m_i$$

$$S_{gen} =$$

* S_{gen} :

* S_{gen} ?

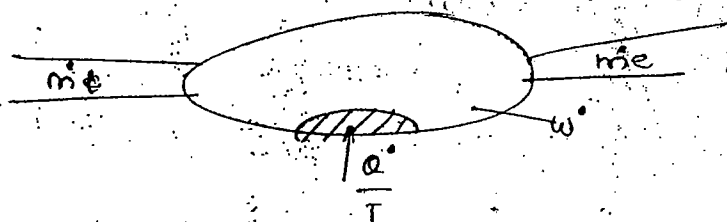
closed system
not transfer
heat or
mass energy

100% conversion of work to heat is possible where as
100% conversion of heat to work is not possible
with work transfer there is no entropy change only with
heat transfer entropy change is associated

entropy change as a result of reversible heat
transfer is called entropy of flow and does not involve
any entropy of generation. reverse process always occurs
in a direction of increase in entropy.

The principle of conservation of entropy is not valid and
entropy of generation in a open system

Entropy of Generation in a open system



$$\sum_i \dot{m}_i = \sum_e \dot{m}_e = \frac{\partial H}{\partial t}$$

$$\sum_i \dot{m}_i \left(h + \frac{V^2}{2} + gz \right) - \sum_e \dot{m}_e \left(h + \frac{V^2}{2} + gz \right)$$

$$+ \dot{Q} - \dot{W} = \frac{\partial E}{\partial t} \quad \text{--- 1st law}$$

$$\sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \frac{\dot{Q}}{T} \leq \frac{\partial S}{\partial t} \quad \text{--- 2nd law}$$

$$S_{gen} = S_{production} = \frac{\partial S}{\partial t} - \sum_i \dot{m}_i s_i + \sum_e \dot{m}_e s_e - \frac{\dot{Q}}{T}$$

* $S_{gen} = 0$ is called a reversible process

* $S_{gen} > 0$ is called a irreversible process.

entropy
ie entropy

100 steady state condition

$$\sum_i \dot{m}_i = \sum_e \dot{m}_e$$

$$\frac{\partial E}{\partial t} = 0 = \dot{Q} - \dot{W} + \sum_i \dot{m}_i \left(h + \frac{V^2}{2} + gz \right) - \sum_e \dot{m}_e \left(h + \frac{V^2}{2} + gz \right)$$

$$\frac{\partial S}{\partial t} = \sum_i \dot{m}_i s_i + \sum_e \dot{m}_e s_e - \frac{\dot{Q}}{T} = S_{gen}$$

for steady state condition

$$\dot{m}_i = \dot{m}_e = \dot{m}$$

$$\frac{\partial S}{\partial t} = 0$$

$$\dot{m} (s_e - s_i) - \frac{\dot{Q}}{T} = S_{gen}$$

$$\dot{m} (s_e - s_i) = \frac{\dot{Q}}{T} + S_{gen}$$

$$(s_e - s_i) = \frac{\dot{Q}}{\dot{m} T} + \frac{S_{gen}}{\dot{m}}$$

what is

Orderly energy: It can be readily converted into disorderly energy but

disorderly energy can be converted into orderly energy there is natural limitation which is given by 3rd law of thermodynamics.

Entropy is degree of randomness, degree of disorder

Entropy is the degree of disorder Boltzmann dynamic F

if 14

Third law Entropy absolute Nernst

Lt $\Delta t \rightarrow 0$

pg 13 qu. 1

$\frac{1}{T}$

$$\oint \frac{dq}{T} =$$

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2}$$

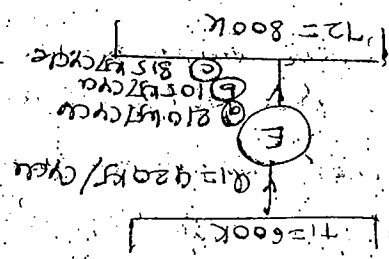
$$\frac{6}{800} + \frac{2}{60}$$

cycle (a)

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2}$$

$$= \frac{420}{600} - \frac{210}{300} = 0$$

Reversible



cycle (b)

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2}$$

$$= \frac{420}{600} - \frac{105}{300} = 0.25$$

Irreversible

cycle (c)

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} - \frac{Q_3}{T_3}$$

$$= \frac{420}{600} - \frac{315}{300} - \frac{60}{800} = -0.35$$

Irreversible

First Law:

$$\Sigma Q = \Sigma W$$

$$Q_1 + Q_2 + Q_3 = W$$

$$5000 + Q_2 + Q_3 = 840$$

$$Q_2 + Q_3 = -4160 \text{ kJ}$$

condition is reversible engine

$$\oint \frac{dQ}{T} = 0$$

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2} + \frac{Q_3}{T_3} = 0$$

$$\therefore \frac{5000}{600} + \frac{Q_2}{300} + \frac{Q_3}{200} = 0$$

$$2Q_2 + 3Q_3 = -7500$$

$$\left[\begin{matrix} Q_2 = -4980 \text{ J} \\ Q_3 = -820 \text{ J} \end{matrix} \right] \text{ or}$$

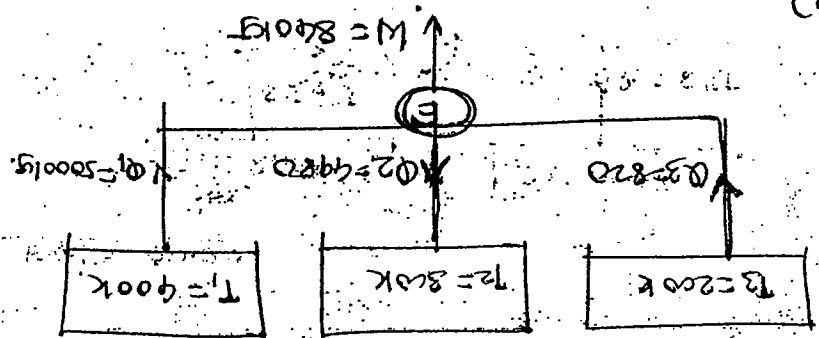
(ds)

(ds)₂ = 0

(ds)₁ = m cp

$$T_2 = 22$$

$$T_1 = 29$$



system

Entropy is randomness or degree of disorder, higher the degree of disorder higher is the entropy
 disorder due to heat flow may result in entropy
 Boltzmann try to define disorder in terms of thermodynamic probability and given the law

$$S = k \ln W$$

k = Boltzmann constant

W = thermodynamic probability of disarrangement

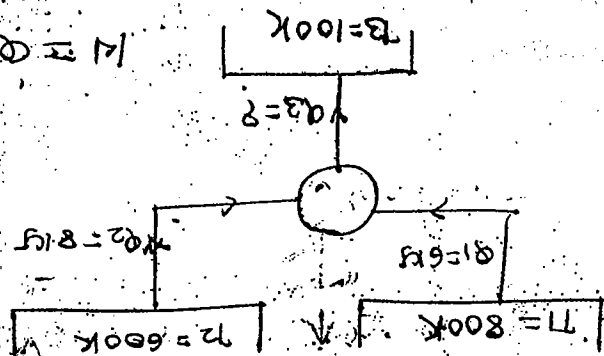
if $W = 1$, $S = 0$ called on greatest order

Third law of thermodynamics

Entropy of pure crystalline substance at absolute zero temperature is zero

Nernst-Simon's statement of IIIrd law

$$\lim_{T \rightarrow 0} \Delta S = 0$$



$$P_1 V_1^{1.2} = P_2 V_2^{1.2}$$

$$\oint \frac{dQ}{T} = 0$$

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2} - \frac{Q_3}{T_3} = 0$$

$$\frac{6}{800} + \frac{8}{600} - \frac{Q_3}{100} = 0$$

$$Q_3 = 2.083 \text{ mJ}$$

$$\eta_{th} = \frac{W}{Q_1} = \frac{6+8}{6} = 85\%$$

Q. 18

Reservoir $T_1 = 373\text{K}$

$Q = m c_p (T_1 - T_2)$

System $T_2 \rightarrow 273\text{K} \rightarrow 373\text{K}$

$(\Delta S)_{\text{reservoir}} = - \frac{m c_p (T_1 - T_2)}{T_1}$

$(\Delta S)_{\text{system}} = m c_p \ln \frac{T_1}{T_2}$

$(\Delta S)_{\text{universe}} = (\Delta S)_{\text{reservoir}} + (\Delta S)_{\text{system}}$

$= m c_p \left[\ln \frac{T_1}{T_2} - \left(\frac{T_1 - T_2}{T_1} \right) \right]$

$= 1 \times 4.18 \left[\ln \left(\frac{373}{273} \right) - \left(\frac{373 - 273}{373} \right) \right]$

$= 4.18 \left[\ln(1.36) - 0.2680 \right]$

$= 4.18 \left[0.307 \right]$

$= 0.18462 \text{ kJ/K}$

$T_1 = 400\text{K}$

$Q_1 = 5000 \text{ J}$

$T_1 = 273\text{K}$

$Q = m c_p (T_1 - T_2)$

$T_2 = 273 \rightarrow 323$

$T_1 = 373$

$Q = m c_p (T_1 - T_2)$

$T_2 = 323 \rightarrow 373$

$(ds)_I = m c_p \left[\ln \frac{T_1}{T_2} - \left(\frac{T_1 - T_2}{T_1} \right) \right] = 1 \times 4.18 \left[\ln \frac{373}{273} - \left(\frac{373 - 273}{373} \right) \right] = 0.0560 \text{ kJ/K}$

$(ds)_II = m c_p \left[\ln \frac{T_1}{T_2} - \left(\frac{T_1 - T_2}{T_1} \right) \right] = 4.18 \left[\ln \frac{373}{323} - \left(\frac{373 - 323}{373} \right) \right]$

$= 0.04135 \text{ kJ/K}$

$(ds)_{\text{universe}} = (ds)_I + (ds)_II = 0.0560 + 0.04135 = 0.09735$

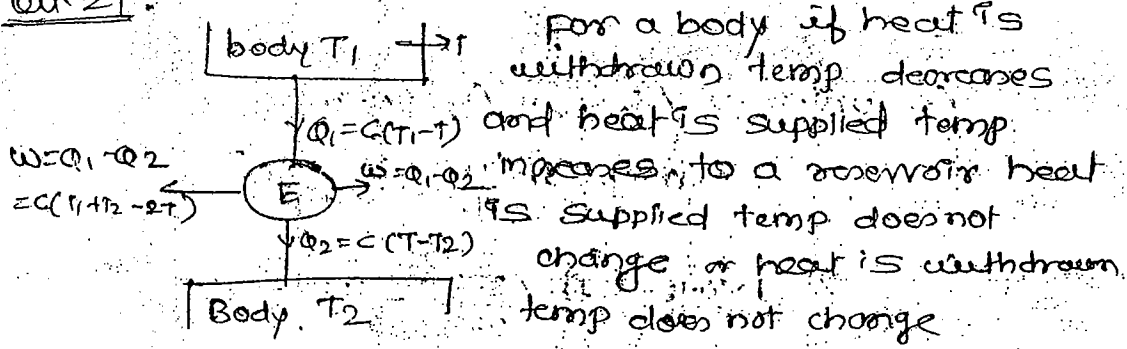
when compared to single stage heating $(\Delta S)_{universe}$ is less hence for 2nd case irreversibility is less. So no. of stages of heating gas are increasing the $(\Delta S)_{universe}$ goes on decreasing, by increasing the no. of stage of heating, infinitely water can be heated without any change in Δ entropy of universe

QUESTION -

Q.1.20:

$$W = Q_1 - Q_2$$

Q.1.21:



heat capacity = mass x specific heat.

Max work is possible engine is reversible

For the condition of reversibility, entropy change of universe must be zero

$$(\Delta S)_{1st\ body} = C \ln \left(\frac{T}{T_1} \right) =$$

$$(\Delta S)_{2nd\ body} = C \ln \left(\frac{T}{T_2} \right) =$$

$$(\Delta S)_{universe} = (\Delta S)_I + (\Delta S)_II = C \ln \frac{T_2}{T_1 T_2}$$

$$C \ln \frac{T_2}{T_1 T_2} = 0$$

$$\ln \frac{T_2}{T_1 T_2} = 0$$

$$\ln \frac{T_2}{T_1 T_2} = \ln 1$$

$$T_2 = T_1 T_2$$

$$T = \sqrt{T_1 T_2} = \frac{T_2}{T_1 T_2} = 1$$

$$(\Delta S)_{I\ body}$$

$$(\Delta S)_{II\ body}$$

$$(\Delta S)_{universe}$$

For min
han to be
must be

1r

Q.81.10
IInd case

$$W_{\max} = C (T_1 + T_2 - 2\sqrt{T_1 T_2})$$

$$= C [\sqrt{T_1} - \sqrt{T_2}]^2$$

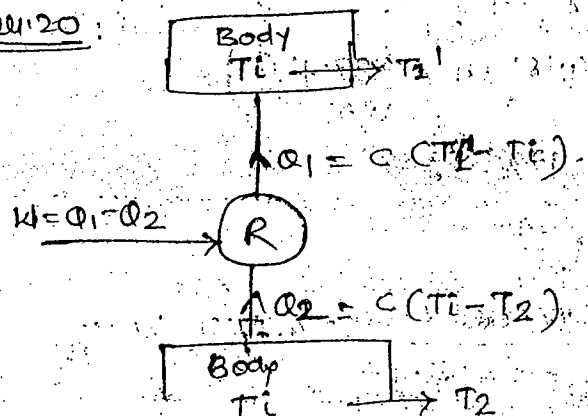
long gas

expanding

intely

Δ entropy

Q.120



at T_s

process

temp

or heat

not

withdrawn

2

specific heat

age of

$$W_{\text{work}} = Q_1 - Q_2 = C [T_1' - T_i] - C [T_i - T_2]$$

$$= C [T_1' + T_2 - 2T_i]$$

$$(\Delta S)_{\text{I body}} = C \ln \frac{T_1'}{T_i}$$

$$(\Delta S)_{\text{II body}} = C \ln \frac{T_2}{T_i}$$

$$(\Delta S)_{\text{universe}} = (\Delta S)_{\text{I}} + (\Delta S)_{\text{II body}}$$

$$= C \ln \frac{T_1' T_2}{T_i^2}$$

For min workdone condition the engine refrigerator has to be reversible for condition reversibility $(\Delta S)_{\text{universe}}$ must be zero

$$\ln \frac{T_1' T_2}{T_i^2} = 0 = \ln 1$$

$$\frac{T_1' T_2}{T_i^2} = 1$$

$$T_1' = \frac{T_i^2}{T_2}$$

$$W_{\min} = C \left[\frac{T_i^2}{T_2} + T_2 - 2T_i \right]$$

Q11.3f

0.7 MPa
water 0°C T_1
 $\downarrow$
water 164.97°C T_2
 $\downarrow$
Steam 164.97°C

$$\Delta S_1 = m c_p \ln \frac{T_2}{T_1}$$

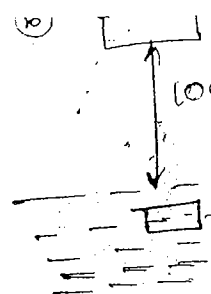
$$= 1 \times 4.182 \ln \left(\frac{437.97}{273} \right)$$

$$= 1.979 \text{ J/K}$$

$$dS_2 = \frac{m L}{T}$$

$$= \frac{1 \times 2066.3}{273 + 164.97} = 4.717 \text{ J/K}$$

$$\Delta S = \Delta S_1 + \Delta S_2 = 1.979 + 4.717 = 6.69 \text{ J/K}$$



$(\Delta S)_{\text{univ}}$

① 100°C
 $C=1$

$(\Delta S)_1 =$

$(\Delta S)_2 =$

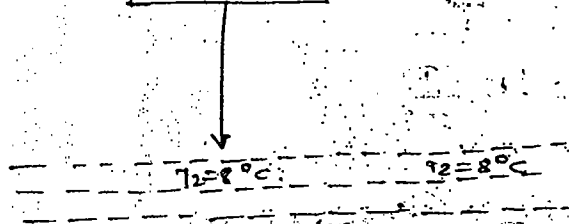
$(\Delta S)_{\text{univ}}$

② $T_1 =$

Q1.14

$m = 600 \text{ gm}$
 $c_p = 150 \text{ J/K}$

$T_1 = 100^\circ\text{C}$



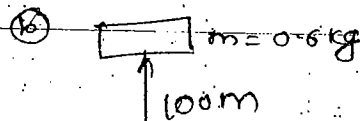
$$(dS)_{\text{river}} = \frac{dQ}{T_2} = \frac{C(T_1 - T_2)}{T_2} = \frac{150(100 - 8)}{281} = 49.11 \text{ J/K}$$

$$(dS)_{\text{block}} = \int_{T_1}^{T_2} \frac{dQ}{T} = C \ln \frac{T_2}{T_1} = 150 \ln \frac{273 + 8}{273 + 100} = -42.48 \text{ J/K}$$

$$(dS)_{\text{universe}} = (dS)_{\text{river}} + (dS)_{\text{block}}$$

$$= 49.11 - 42.48$$

$$= 6.63 \text{ J/K}$$



$$(\Delta S)_{\text{block}} = 0$$

$$(\Delta S)_{\text{river}} = \frac{mgh}{T}$$

$$= \frac{0.6 \times 9.81 \times 100}{281}$$

$$= \underline{2.094 \text{ J/K}}$$

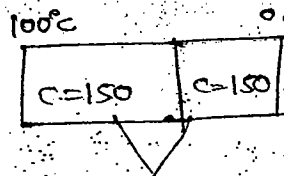
$$(\Delta S)_{\text{universe}} = (\Delta S)_{\text{block}} + (\Delta S)_{\text{river}}$$

$$= \underline{2.094 \text{ J/K}}$$

$$= 1.4 \text{ J/K}$$

$$12 = \underline{6.69 \text{ J/K}}$$

⑪



$$T_f = \frac{T_1 + T_2}{2} = \frac{100 + 0}{2} = 50^\circ\text{C}$$

$$(\Delta S)_2 = C \ln \frac{T_f}{T_1} = 150 \times \ln \left(\frac{323}{373} \right) = -21.588 \text{ J/K}$$

$$(\Delta S)_1 = C \ln \frac{T_f}{T_2} = 150 \ln \left(\frac{323}{273} \right) = 25.22 \text{ J/K}$$

$$(\Delta S)_{\text{universe}} = (\Delta S)_1 + (\Delta S)_2$$

$$= -21.588 + 25.22 = \underline{3.632 \text{ J/K}}$$

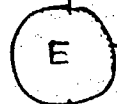
$$= 49.11 \text{ J/K}$$

$$\frac{+8}{+100} = -42.48 \text{ J/K}$$

⑫

$$T_1 = 250 + 273 = 523 \text{ K}$$

$$Q_1 = T_1 \Delta S = 523 \times 1.44 = 897.12$$



$$W = ?$$

$$T_2 = 293 + 27 = 320$$

$$W = \eta Q_1$$

$$= \frac{T_1 - T_2}{T_1} \times Q_1$$

$$= \frac{T_1 - T_2}{T_1} \times T_1 \Delta S$$

$$= (T_1 - T_2) \Delta S$$

$$= (523 - 320) \times 1.44$$

$$= \underline{465.12 \text{ J/K}}$$

$$\text{power (kW)} = \dot{m}_S (\text{kg/sec}) w (\text{kJ/kg})$$

$$20 = \dot{m}_S \times 465.1$$

$$\dot{m}_S = \frac{20}{465.1} = 0.043 \text{ kg/sec.}$$

$$\textcircled{11} \quad C_p = a + bT$$

$$dq = \int_{T_1}^{T_2} C_p dT = \int_{T_1}^{T_2} (a + bT) dT = aT \Big|_{T_1}^{T_2} + \frac{bT^2}{2} \Big|_{T_1}^{T_2}$$

$$dQ = a(T_2 - T_1) + \frac{b(T_2^2 - T_1^2)}{2}$$

$$ds = \int_{T_1}^{T_2} \frac{dQ}{T} = \int_{T_1}^{T_2} \frac{C_p dT}{T} = \int_{T_1}^{T_2} \frac{(a + bT) dT}{T}$$

$$= a \ln T \Big|_{T_1}^{T_2} + bT \Big|_{T_1}^{T_2}$$

$$= a \ln \left(\frac{T_2}{T_1} \right) + b(T_2 - T_1)$$

$$C_p = a + bT$$

$$25.2 \times 10^3 \text{ J } T = 500 \text{ K}$$

$$C_p = 80.1 \times 10^3, T = 1200 \text{ K}$$

$$25.2 \times 10^3 = a + 500b$$

$$80.1 \times 10^3 = a + 1200b$$

$$\boxed{a = 21700} \quad \boxed{b = 7}$$

$$dQ = 21700 (1200 - 500) + \frac{7(1200^2 - 500^2)}{2}$$

$$= 15.19 \times 10^6 + 4.165 \times 10^6$$

$$= 19.355 \times 10^6$$

$$ds = 21700 \ln \left(\frac{1200}{500} \right) + 7(1200 - 500)$$

$$= 18.997 \times 10^3 + 4900$$

$$= 23897.6 \text{ J/K}$$

ΔS

$m_1 =$

$m_2 =$

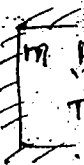
$n =$

$x_1 =$

$x_2 =$

(ΔS)

only
mixing
entropy



$m = m$

$$(\Delta S)_{\text{universe}} = -0.088 + \frac{28.5 - W}{273}$$

$$0 = -0.088 + \frac{28.5 - W}{273}$$

$$W = 4.476$$

Qu. 8
max

$$T_1 = 20^\circ\text{C} \quad \underline{\text{H}_2\text{O}}$$



$$T_2 = 0^\circ\text{C} \quad \underline{\text{H}_2\text{O}}$$



$$T_2 = 0^\circ\text{C} \quad \underline{\text{Ice}}$$



$$T_3 = -10^\circ\text{C} \quad \underline{\text{Ice}}$$

$$ds_1 = m c_p \ln \frac{T_2}{T_1}$$

$$= 10 \times 4.2 \times \ln \frac{273}{293}$$

$$= -2.96 \text{ J/K}$$

$$ds_2 = \frac{-m L_{\text{ice}}}{T_2}$$

(-ve removing)

$$= \frac{-10 \times 335}{273} = -12.27$$

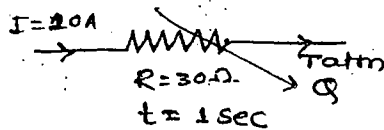
variable temp process integral

$$ds_3 = m \cdot c_{p, \text{ice}} \ln \frac{T_3}{T_2}$$

$$= 10 \times 2.1 \ln \left(\frac{263}{273} \right) = -0.78 \text{ J}$$

$$(\Delta S)_{\text{universe}} = ds_1 + ds_2 + ds_3 = -2.96 - 12.27 - 0.78 = -16.01 \text{ J/K}$$

Qu. 7



$$(ds)_{\text{res}} = 0$$

$$(ds)_{\text{surrounding}} = \frac{I^2 R t}{T_{\text{room}}}$$

$$= \frac{(10)^2 \times 30 \times 1}{300}$$

$$= 10 \text{ J/K}$$

$$(\Delta S)_{\text{universe}} = (ds)_{\text{resistor}} + (ds)_{\text{surrounding}}$$

$$(\Delta S)_{\text{universe}} = 10$$

$$\frac{28.5 - W}{273}$$

has to be
by the

$I = 10 \text{ A}$
 $R = 20 \Omega$
 $t = 1 \text{ sec}$
 $Q = 0$

$$I^2 R t = \text{mass of wire} \times c_p \text{ wire} (T_2 - T_{\text{atm}})$$

$$I^2 R t = m_w \times c_{pw} (T_2 - T_{\text{atm}})$$

$$(10)^2 \times 20 \times 1 = 10 \times 10^3 \times 0.9 \times 10^3 (T_2 - 300)$$

$$\boxed{T_2 = 633.33 \text{ K}}$$

$$(\Delta S)_{\text{wire}} = m_w c_{pw} \ln \frac{T_2}{T_1}$$

$$= 10 \times 10^3 \times 0.9 \times 10^3 \times \ln \frac{633}{300}$$

$$= \underline{\underline{6.720 \text{ J/K}}}$$

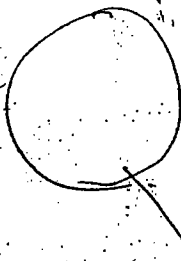
$$(\Delta S)_{\text{surrounding}} = 0$$

$$(\Delta S)_{\text{universe}} = (\Delta S)_{\text{wire}} + (\Delta S)_{\text{surrounding}}$$

$$= 6.720 + 0 = \underline{\underline{6.72}}$$

Q11.6

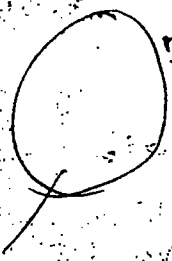
$m_1 = 2 \text{ kg}$
 $T_1 = 80^\circ \text{C}$



T_f

$m_2 = 3 \text{ kg}$

$T_2 = 30^\circ \text{C}$



$$m_1 c_{pw} (T_1 - T_f) = m_2 c_{pw} (T_f - T_2)$$

$$2(80 - T_f) = 3(T_f - 30)$$

$$T_f =$$

$$160 - 2T_f = 3T_f - 90$$

$$\boxed{T_f = 50^\circ \text{C}} = 323 \text{ K}$$

4th)

$$(\Delta S)_{\text{I water}} = m_1 \cdot c_{pw} \ln \frac{T_b}{T_1} = 2 \times 4.187 \ln \frac{323}{303} \\ = \underline{-0.7437 \text{ J/K}}$$

$$(\Delta S)_{\text{II water}} = m_2 c_{pw} \ln \frac{T_b}{T_2} = 3 \times 4.187 \ln \frac{323}{303} \\ = \underline{0.9278 \text{ J/K}}$$

$$(\Delta S)_{\text{universe}} = (\Delta S)_{\text{I}} + (\Delta S)_{\text{II}} \\ = -0.7437 + 0.9278 \\ = \underline{0.1841 \text{ J/K}}$$

Ques: $(\Delta S)_{\text{mixing}} = (\Delta S)_{\text{separation}}$

In isothermal process, $T = C$

$$\boxed{dQ = dW}$$

$$dQ = T(dS)_{\text{mixing}} \quad dS$$

$$X_{N_2} = 0.79$$

$$X_{O_2} = 0.21$$

$$(\Delta S)_{\text{mixing}} = -nR \sum x_i \ln x_i$$

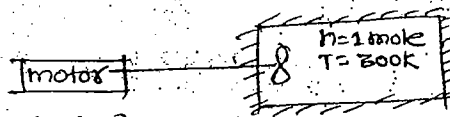
$$= -nR [x_{N_2} \ln x_{N_2} + x_{O_2} \ln x_{O_2}]$$

$$= -1 \times 8.314 [0.79 \ln 0.79 + 0.21 \ln 0.21]$$

$$= -1 \times 8.314 [-0.18622 + 0.3222]$$

$$= \underline{4.2722}$$

$$dW = dQ = T(dS) = 300 \times 4.2722 = 1281.66$$



$$P=60W$$

$$t=120s$$

$$\dot{w} = 18.956 + 4.93 \times 10^{-3} T$$

$$dQ = dQ - dW = dU = C_V dT \quad T_2$$

$$0 - P \Delta T = 0 - (P \Delta T) = \int_{300}^{T_2} (18.956 + 4.93 \times 10^{-3} T) dT$$

$$60 \times 120 = \left[18.956 T \right]_{300}^{T_2} + \left[4.93 \times 10^{-3} \frac{T^2}{2} \right]_{300}^{T_2}$$

$$= 18.956 (T_2 - 300) + 4.93 \times 10^{-3} (T_2^2 - 300^2)$$

$$7200 = 18.956 T_2 - 5686.8 + 4.93 \times 10^{-3} T_2^2 - 443.7$$

$$7200 = -6130.5 + 18.956 T_2 + 4.93 \times 10^{-3} T_2^2$$

$$4.93 \times 10^{-3} T_2^2 + 18.956 T_2 - 13330.5 = 0$$

$$T_2 = 638K, -8328K$$

$$ds = \int_{T_1}^{T_2} \frac{n C_V dT}{T} = \int_{300}^{638} \frac{(18.956 + 4.93 \times 10^{-3} T) dT}{T}$$

$$= \left[18.956 \ln T \right]_{300}^{638} + \left[4.93 \times 10^{-3} T \right]_{300}^{638}$$

$$= 18.956 \ln(638/300) + 4.93 \times 10^{-3} (638 - 300)$$

$$= 16.381 +$$

$$= 16.95$$

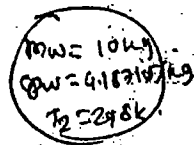
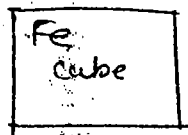
Q1.2:

mic

cpi

$$T_i = 460^\circ C$$

$$T_f = 673K$$



$$T_f = 50^\circ$$

$$\text{Heat lost} = \text{Heat gained}$$

$$m_i c_{pi} (T_i - T_f) = m_w c_{pw} (T_f - T_2)$$

$$m_i c_{pi} (673 - T_f) = 10 \times 4187 (T_f - 298)$$

$$(\text{given}) T_f = 50 + 273 = 323$$

$$m_i c_{pi} = 2.98$$

$$(ds)_{\text{iron}} = m_i c_{pi} \ln \frac{T_f}{T_i} = 2.98 \ln \frac{323}{673} = -2.18759$$

$$(ds)_{\text{iron}} = m_w c_{pw} \ln \frac{T_f}{T_2} = 10 \times 4.187 \ln \frac{323}{298} = 3.37$$

$$(\Delta S) (\Delta S)_{\text{universe}} = (ds)_{\text{iron}} + (ds)_{\text{iron}} = 1.1870 \text{ hence it is irreversible process}$$

$$793 \times 10^3 T) dT$$

$$2.7 T_2$$

$$- (300^2)$$

$$- 443.7$$

Q1.1

$$\begin{aligned} PV &= 0.287 T \\ V_1 &= 0.287 T_1 \\ &= \frac{0.287 \times 293}{700} \\ &= 0.12 \frac{\text{m}^3}{\text{kg}} \end{aligned}$$

$$\begin{aligned} V_2 &= \frac{0.287 P_2}{P_2} \\ &= \frac{0.287 \times 333}{350} \\ &= 0.273 \text{ m}^3/\text{kg} \end{aligned}$$

process 1-2 $P=c$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

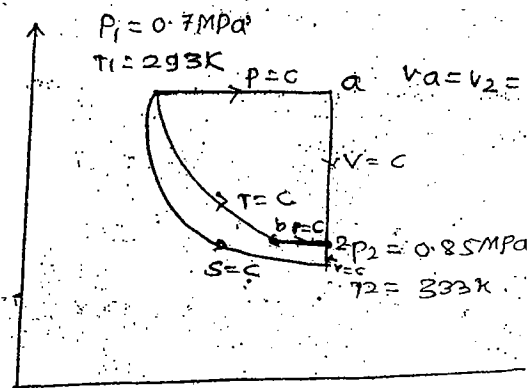
$$\frac{0.12}{293} = \frac{0.273}{T_2}$$

$$T_2 = 666.57 \text{ K}$$

$$S_a = c_p \ln \frac{T_2}{T_1} = 1005 \ln \frac{666.57}{293} = 0.82 \text{ kJ/K}$$

$$S_2 = c_v \ln \frac{T_2}{T_1} = 0.718 \ln \frac{666}{293} = 0.498 \text{ kJ/K}$$

$$S_2 = S_a + S_2 = 0.328 \text{ kJ/K}$$



1-b-2

1-b I=e

$$I_{Sb} = R \ln \frac{p_a}{p_b} = R \ln \frac{V_b}{V_a} = 0.287 \ln \left(\frac{0.35}{700} \right) = +0.198 \text{ kJ/K}$$

$$b_{S2} = c_p \ln \frac{T_2}{T_b} = 1.005 \ln \frac{333}{293} = 0.12860 \text{ kJ/K}$$

$$I_{S2} = I_{Sb} + b_{S2} = 0.328 \text{ kJ/K}$$

1-c-2

$$\underline{1-c} = S=c \quad I_{Sc} = 0$$

$$T_1 V_1^{r-1} = T_2 V_2^{r-1}$$

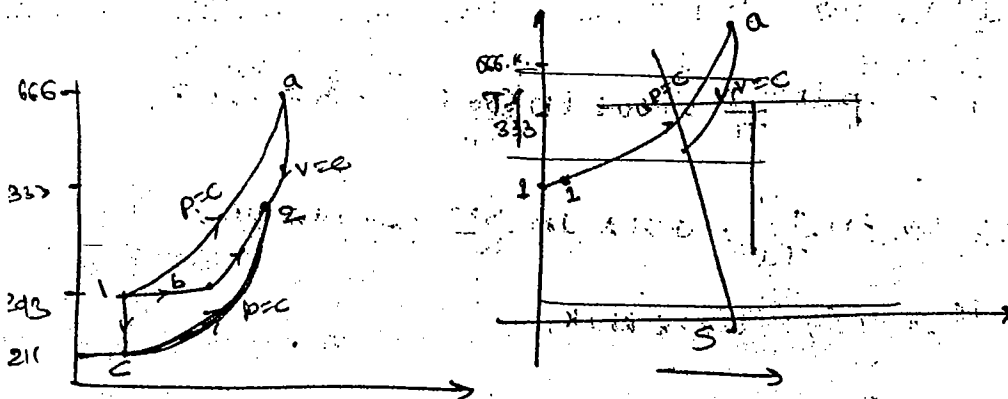
$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{r-1} = 293 \times \left(\frac{0.12}{0.273} \right)^{0.4} = 210.89 \text{ K}$$

$$c_{S2} = c_v \ln \frac{T_2}{T_c} = 0.718 \ln \frac{333}{211} = 0.3226$$

$$I_{S2} = I_{Sc} + c_{S2} = 0 + 0.322 = 0.322 \text{ kJ/K}$$

It is point function not path fn

In all the cases the ΔS change is same which proves that entropy is point function and it is independent of the path followed.



ex 10

$$m_{Cu} = 0$$

$$\dot{Q}_{Cu} = 0.6 \text{ kJ/s}$$

$$T_1 = 20^\circ \text{C}$$

let $x = h_e$

$y = h_c$

if $x > y$
in br

if $x = y$

if $x < y$
melt

$$x = 100$$

$$y = 10$$

$$x > y$$

temp is 1

md

$$= 0.757$$

$$= 6.27$$

$$=$$

(ds) calc

$$\ln\left(\frac{0.35}{700}\right)$$

kJ/K

or

rich more
ent of

Q145:

$$m_{cu} = 0.75 \text{ kg}$$

$$C_{p,cu} = 0.418$$

$$T_i = 20^\circ\text{C}$$

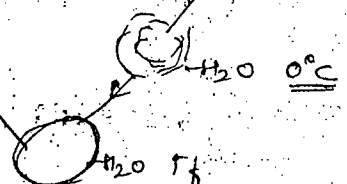
$$m_w = 0.2 \text{ kg}$$

$$C_{p,w} = 4.18$$

ice

$$m_i = 0.05 \text{ kg}$$

$$\text{Latent heat} = 333 \text{ kJ/kg}$$



Let

x = heat required to cool the water & calorimeter to 0°C

y = heat required to completely melt the ice at water at

If $x > y$, entire ice will melt and the resultant temp is in between 0 to 20°C

If $x = y$ the ice completely melts and resultant temp is

If $x < y$, resultant temp is 0°C on only the portion of ice melt and remaining ice is in ice form

$$x = m_{cu} C_{p,cu} (T_i - 0) + m_w C_{p,w} (T_i - 0) =$$

$$= (0.75 \times 0.418 + 0.2 \times 4.18) (20) = 22.99 \text{ kJ}$$

$$y = m_i L_{ice} = 0.05 \times 333 = 16.65 \text{ kJ}$$

$x > y$ the entire ice will melt and the resultant temp is between 0 to 20

$$m_{cu} C_{p,cu} (T_i - T_f) + m_w C_{p,w} (T_i - T_f) = m_{ice} L_{ice} + m_{ice} C_{p,w} (T_f - 0)$$

$$= 0.75 \times 0.418 (20 - T_f) + 0.2 \times 4.18 (20 - T_f) = 0.05 \times 333 + 0.05 \times 4.18 \times T_f$$

$$= 6.27 - 0.3135 T_f + 16.72 - 0.236 T_f = 199.85 + 0.200 T_f$$

$$T_f = 4.67^\circ\text{C}$$

$$(ds)_{\text{calorimeter}} = m_{cu} C_{p,cu} \ln \frac{T_f}{T_i}$$

$$= 0.75 \times 0.418 \times \ln \left(\frac{273 + 4.67}{273 + 20} \right)$$

$$= -0.01684 \text{ kJ/K}$$

$$(ds)_{\text{water}} = m_w c_{pw} \ln \frac{T_b}{T_1} = 0.2 \times 4.18 \times \ln \frac{293+4.67}{293+20} = -0.044$$

$$(ds)_{\text{ice}} = \frac{m_{\text{ice}} L_{\text{ice}}}{T_2} + m_{\text{ice}} c_{p\text{water}} \ln \frac{T_b}{T_2}$$

$$= \frac{0.05 \times 333}{293} + 0.05 \times 4.18 \ln \left(\frac{4.67}{293} \right)$$

$$= 0.06698 - 0.85027$$

$$= -0.78 \quad 0.0645 \text{ kJ/K}$$

$$(ds)_{\text{system}} = (ds)_{\text{calor}} + (ds)_{\text{water}} + (ds)_{\text{ice}}$$

$$= -0.01684 + (-0.0549) + 0.0645$$

$$(ds)_{\text{surrounding}} = 0$$

$$(ds)_{\text{universe}} = (ds)_{\text{sys}} + (ds)_{\text{Surr}} = 3.60 \times 10^{-3} > 0$$

hence it is reversible process

$$\text{min work} = T \Delta s \quad T_1 = 20^\circ\text{C}$$

Q19-N=20

Q19

$$m_{\text{ice}} = 1.5 \text{ kg} \quad c_{p\text{ice}} = 2.09 \quad T_1 = 260 \text{ K}$$

$$\downarrow Q_1 = m c_{p\text{ice}} (T_2 - T_1)$$

$$T_2 = 273 \text{ K ice}$$

$$\downarrow Q_2 = m L_{\text{ice}}$$

$$T_2 = 273 \text{ K H}_2\text{O}$$

$$\downarrow Q_3 = m c_{p\text{H}_2\text{O}} \Delta T$$

$$T_3 = 293 \text{ K H}_2\text{O}$$

$$Q_1 = m c_{p\text{ice}} (T_2 - T_1)$$

$$= 1.5 \times 2.09 (273 - 260)$$

$$= 40.365 \text{ kJ}$$

$$Q_2 = m L_{\text{ice}} = 1.5 \times 334 = 500.1$$

$$Q_3 = m c_{p\text{H}_2\text{O}} \Delta T$$

$$= 1.5 \times 4.2 (293 - 273)$$

$$= 126 \text{ kJ}$$

$$(Q_1) = \dots$$

$$(ds_2) = \dots$$

$$(ds_3) = \dots$$

$$(\Delta S)_{\text{system}}$$

$$Q = Q_1$$

$$(S_2 - S_1)$$

$$2.421$$

$$\text{pg. No 16}$$

$$\Delta ds =$$

$$\text{Q19}$$

$$T \uparrow$$

$$\text{Q19}$$

$$T$$

$$\frac{4.67}{+20} = \underline{0.044}$$

$$(ds_1) = m \cdot c_p \ln \frac{T_2}{T_1} = 1.5 \times 2.07 \ln \left(\frac{293}{260} \right) = \underline{0.1574 \text{ KJ}}$$

$$(ds_2) = \frac{m \cdot L_{ice}}{2} = \frac{1.5 \times 333.4}{2} = \underline{1.83 \text{ KJ/K}}$$

$$(ds_3) = m \cdot c_{pw} \ln \frac{T_3}{T_2} = 1.5 \times 4.2 \ln \left(\frac{293}{293} \right) = \underline{0.445 \text{ KJ/K}}$$

$$(\Delta S)_{system} = ds_1 + ds_2 + ds_3 = \underline{2.4264}$$

$$Q = Q_1 + Q_2 + Q_3 = \underline{666.465 \text{ KJ}}$$

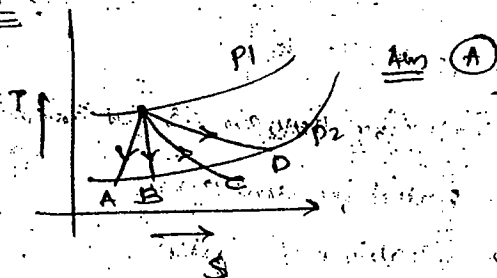
$$(S_2 - S_1) - \int \frac{dQ}{T} = S_{gen} = S_{production}$$

$$2.421 - \frac{666.465}{293} = \underline{0.1463} = S_{gen} = S_{production}$$

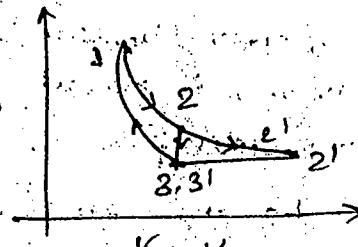
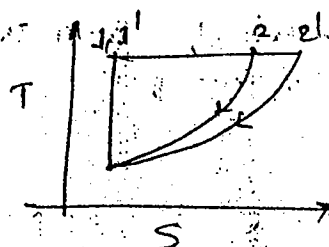
pg. NO 16 Ques 1

$$\Delta ds = \frac{\text{Power} \times \text{time}}{\text{temp}} = \frac{5 \times 2600}{293} = \underline{61.45 \text{ K}}$$

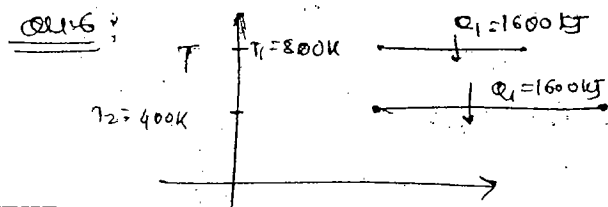
Ques 2



Ques 3



C
p(C₂-T₁)
ice
to
H₂O
ncpw ΔT
H₂O



$$(S_2 - S_1) - \int \left(\frac{dQ}{T} \right) = S_{gen}$$

$$= \frac{1600}{400} - \left[\frac{1600}{800} \right] = S_{gen}$$

$$(ds)_{reser} = -\frac{1600}{800} = -2$$

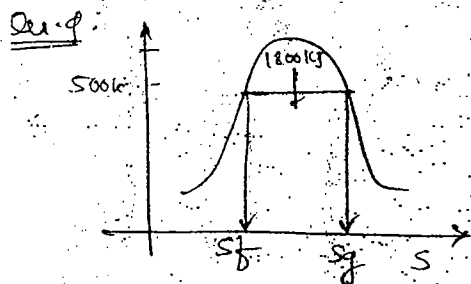
$$(ds)_{system} = \frac{1600}{400} = 4$$

$$(ds)_{universe} = (ds)_{system} + (ds)_{reser} = 2$$

Q1.8:

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = \frac{600}{1000} - \frac{450}{800} = -0.9 \text{ kJ/K}$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{600 - 450}{600} = 25\%$$



$$S_g - S_f = \frac{h_{fg}}{T_{sat}}$$

$$S_g - S_f = \frac{1800}{500}$$

$$S_g = 6.2 \text{ kJ/K}$$

(13) $dQ = du + dw$ eqn is valid for any process for any system

$dQ = du + dw$ eqn is valid for any process undergone by a closed stationary system

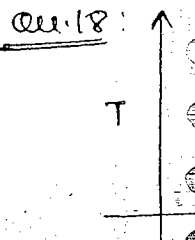
$dQ = du + pdv$ this eqn is valid for closed system when only pdv work is present this is true for reversible quasi-static process.

$Tds = dQ$ This eqn is valid for reversible process.

$Tds = du + pdv$ This eqn is valid for any process reversible or irreversible undergone by a closed system

$Tds = du - vdp$ This eqn holds good for any process since there is no path for in the sequence

Q1.6 (d)
(ds)
(ds)



Q1.22

Q1.24

Pg. No. 47

Pg. No. 48

Q1.9

Q1.11

$$) = S_{gen.}$$

$$= S_{gen}$$

]

$$= -0.9 \text{ kJ/K}$$

1. motor for
any system

2. system

3. process

4. process

5. system

6. any
sequence

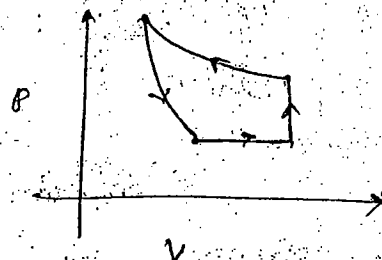
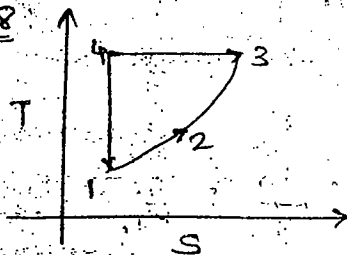
Q16 $(ds)_{system} = 100(0.4 - 0.3) = 10$

$$(ds)_{surrounding} = 75 - 80 = -5$$

$$(ds)_{universe} = (ds)_{system} + (ds)_{surrounding} = 5 > 0$$

irreversible process.

Q18



Q22

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2}$$

$$= \frac{1000}{(285+293)} - \frac{492}{(293+5)}$$

$$= 0.02$$

$$\oint \frac{dQ}{T} > 0 \text{ impossible}$$

Q24 : $Q = \alpha T + \beta T^2$

$$ds = \int \frac{dQ}{T} = \int \frac{d(\alpha T + \beta T^2)}{T}$$

$$= \int_{T_1}^{T_2} \alpha \frac{dT}{T} + \frac{2\beta T dT}{T}$$

$$= \alpha \ln \frac{T_2}{T_1} + 2\beta (T_2 - T_1)$$

Pg. No. 47

Q15

$$dQ - dW = dU$$

$$-2000 - (-5000) = dU$$

$$dU = 2000 \text{ kJ}$$

Pg. No. 48 Q17

(a)

Pg. No. 50

Q1.1

(a)

Q1.8

(d)

Q1.11

0

pg no 50 Qu. 56(c)

$$m = \frac{pV}{RT} = \frac{200 \times 1}{\frac{8.314}{28} \times 298} = 2.26 \text{ kg.}$$

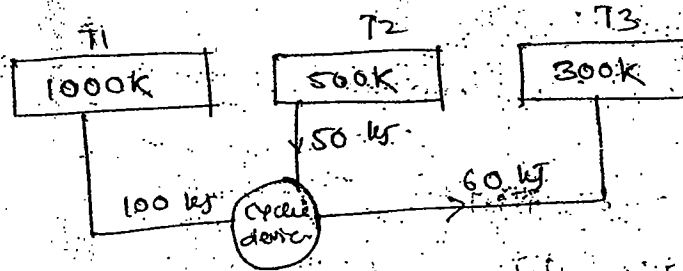
$$\begin{aligned} dQ = dW &= mRT \ln \frac{v_2}{v_1} \\ &= 2.26 \times \frac{8.314}{28} \times 298 \ln \frac{e}{1} \\ &= 138.6 \text{ kJ.} \end{aligned}$$

$$(ds)_{\text{system}} = 0 \quad (ds)_{\text{surrounding}} = \frac{dQ}{T} = \frac{138.6}{298} = 0.4652$$

$$(\Delta S)_{\text{universe}} = 0.4652$$

Qu. 22 pg no 53 E-G-J-K-N (a)
F-H-J-K-M

Qu. 32



$$\begin{aligned} \oint \frac{dQ}{T} &= \frac{Q_1}{T_1} + \frac{Q_2}{T_2} - \frac{Q_3}{T_3} \\ &= \frac{100}{1000} + \frac{50}{500} - \frac{60}{300} = 0 \end{aligned}$$

is reversible engine

High
- Mech
electrical

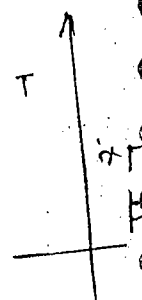
water
wind
of jet

complete
energy
thermo
a cert
available

AE =

K/m

y
x
W



Availability

High grade energy

- Mechanical work,
- electrical energy,
- water power,
- wind power, kinetic energy
- of jet and tidal power

Low grade energy

- heat or thermal energy,
- heat derived from nuclear fission and fusion, heat derived from combustion of fossil fuel.

$$\epsilon = 0.652$$

Complete conversion of low grade energy to high grade energy is impossible and it is limited by 2nd law of thermodynamics. Maximum work output obtainable from a certain heat input in a cycle engine is called as available energy

$$Q_1 = \text{Available energy} + \text{unavailable energy}$$

$$Q_1 = AE + UE$$

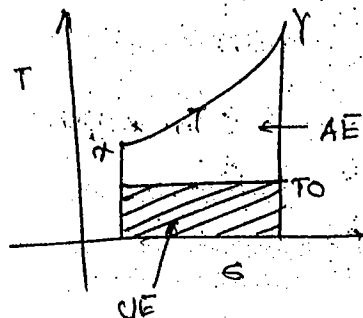
$$W_{\max} = AE = Q_1 - UE$$

$$AE = \text{exergy} \quad UE = \text{anergy}$$

$$W_{\max} = \left(1 - \frac{T_0}{T_1}\right) Q$$

$$\int_x^y dW_{\max} = \int_x^y \left(1 - \frac{T_0}{T_1}\right) dQ_1$$

$$W_{\max} = Q_{xy} - T_0 (S_y - S_x)$$



$$AE = Q_{xy} - T_0 (S_y - S_x)$$

$$UE = T_0 (S_y - S_x) \text{ --- change in entropy}$$

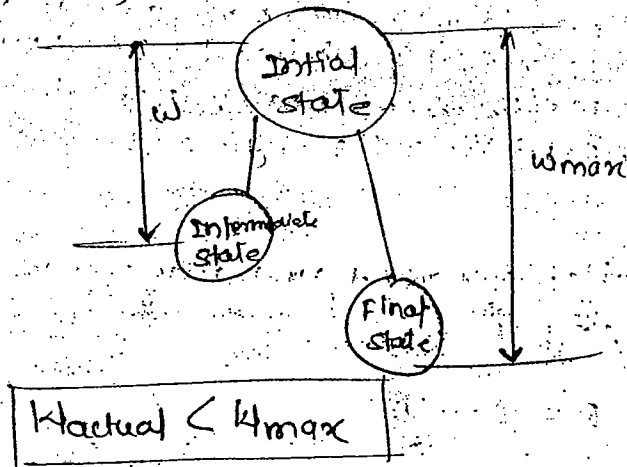
└─ lowest temp

$$W_{\text{work}} = \int \left[\begin{array}{l} \text{initial process} \\ \text{state; path; state} \end{array} \right]$$

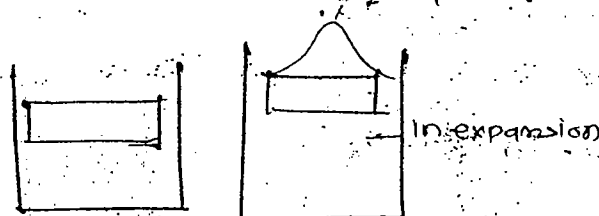
Dead state: Thermodynamic equilibrium with surrounding i.e. thermal & mechanical equilibrium

It is generally $P_0 = 1 \text{ atm}$, $T_0 = 25^\circ\text{C}$

hence, So,



The W_{max} is upper limit on the amount of work a device can deliver without violating any thermodynamic laws.



$$W_U = W - W_{\text{surrounding}}$$

$$= W - P_0(V_2 - V_1)$$

$W_{\text{surrounding}}$

$$W_U = \text{useful}$$

$$\text{Irreversibility} = W_{\text{rev}} - W_U$$

$W_{\text{rev}} > W_{\text{useful}}$ it called as work producing device

$W_{\text{rev}} < W_{\text{useful}}$ Work consuming device.

$Q =$

Δ

$S_2 - S_1$

$\frac{Q}{T_0}$

Q

$W =$

$W =$

W_{useful}

W_U

W_U

Maximum process

S_{gen}

$W_U =$

Available

$Q =$

Δ

Δ

Δ

Availability in closed system

used
with
equilibrium
°C

$$Q - W = U_2 - U_1 \quad \text{--- 1st law for closed syst}$$

$$\Delta S \quad S_{gen} = (S_2 - S_1) - \frac{Q}{T_0}$$

$S_2 - S_1$ = entropy change of system

$\frac{Q}{T_0}$ = entropy of transfer

$$Q = T_0 (S_2 - S_1) - T_0 S_{gen}$$

$$W = Q - (U_2 - U_1)$$

$$W = T_0 (S_2 - S_1) - T_0 S_{gen} - (U_2 - U_1)$$

$$W_{useful} = W - W_{surround} \\ = W - P_0 (V_2 - V_1)$$

$$W_U = T_0 (S_2 - S_1) - T_0 S_{gen} - (U_2 - U_1) + P_0 (V_2 - V_1)$$

of work
y

$$W_U = (U_1 - U_2) + P_0 (V_1 - V_2) - T_0 (S_1 - S_2) - T_0 S_{gen}$$

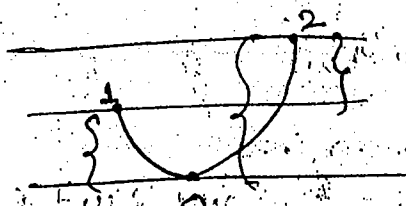
Maximum μ useful work is obtained when the process is reversible and for reversible process $\Delta S_{gen} = 0$

$$W_U = (U_1 - U_2) + P_0 (V_1 - V_2) - T_0 (S_1 - S_2)$$

Availability function for non flow process

= useful

$$\Phi = (U + P_0 V - T_0 S)$$



$$\Phi_1 - \Phi_0 = (U_1 - U_0) + P_0 (V_1 - V_0) - T_0 (S_1 - S_0)$$

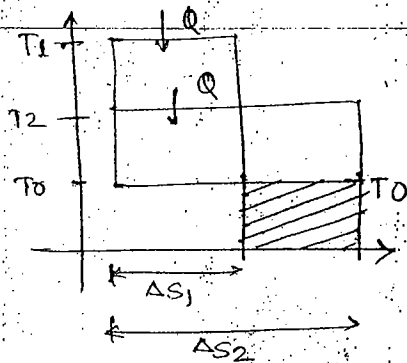
$$\Phi_2 - \Phi_0 = (U_2 - U_0) + P_0 (V_2 - V_0) - T_0 (S_2 - S_0)$$

work

ing

$$\Phi_1 - \Phi_2 = (U_1 - U_2) + P_0 (V_1 - V_2) - T_0 (S_1 - S_2)$$

decrease in available energy when heat is transferred from a higher temp reservoir to a lower temp reservoir



$$Q = T_1 ds_1 = T_2 ds_2$$

$$ds_1 = \frac{Q}{T_1}, ds_2 = \frac{Q}{T_2}$$

$$T_1 > T_2$$

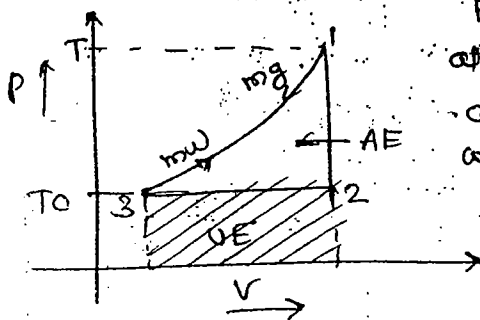
$$ds_2 > ds_1$$

$$W_1 = Q - T_0 ds_1 \quad W_2 = Q - T_0 ds_2 \quad \therefore W_2 < W_1$$

$$\text{Loss work} = W_1 - W_2 = T_0 (ds_2 - ds_1) \quad \leftarrow \text{loss in available energy}$$

Temp difference betⁿ T_1 & T_2 is high the loss in available energy is high. if the difference betⁿ temp is less the loss in available energy is less.

Available energy from a finite energy source



Hot gases m_g are available at temp T which are cooled to T_0 and are used for heating the water from a temp T_0 to T

Heat loss by gases

= Heat gained by water

$$m_g C_{p_g} (T - T_0) = m_w C_{p_w} (T - T_0)$$

$$m_g C_{p_g} = m_w C_{p_w}$$

The heating process is reversible i.e. the temp difference betⁿ the gas and fluid is always zero. then the fluid expands from state 1 to state 2 in turbine and reject heat Q_2 in the process 2-3.

in he

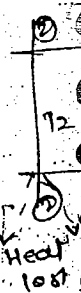
(ds

(ds)

(ds)_{gas}

*Available

Qual



where

section

higher

this

at T_s
 T to a

$\frac{Q}{2}$

$< W_1$

in available
 energy

is in
 our belt
 by is less

Source

available
 added to T_0

high the
 T to T

by water

1)

fluid is
 in state 1
 in the

In the process he does work.

In heating process

$$(ds)_{\text{gas}} = m_g c_{pg} \ln \frac{T}{T_0}$$

$$(ds)_{\text{water}} = m_w c_{pw} \ln \frac{T}{T_0} = m_g c_{pg} \ln \frac{T}{T_0}$$

$$(ds)_{\text{gas}} + (ds)_{\text{water}} = 0 = (\Delta S)_{\text{universe}} \text{ reversible process}$$

$$* \text{Available energy} = Q - T_0 ds$$

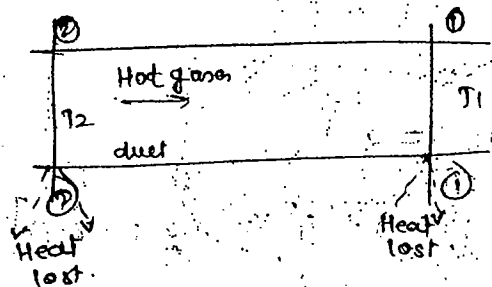
Q - the amount
 then we want
 T_0

$$= m_g c_{pg} (T - T_0) - T_0 m_g c_{pg} \ln \frac{T}{T_0}$$

$$= m_g c_{pg} \left[(T - T_0) - T_0 \ln \frac{T}{T_0} \right]$$

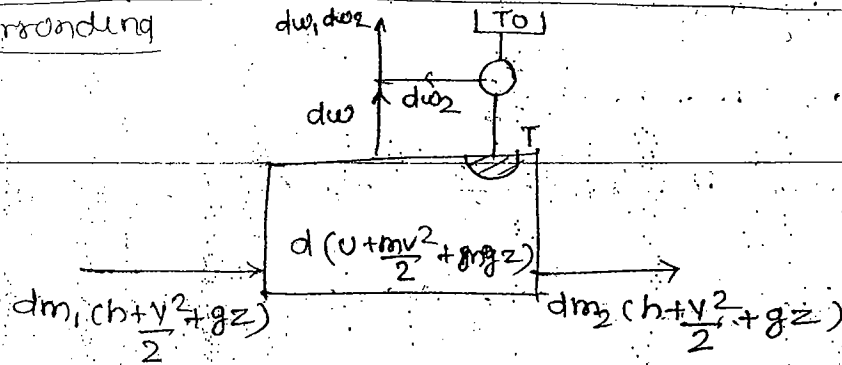
$$m_g c_{pg} \ln \frac{T}{T_0} = m_w c_{pw} \left[(T - T_0) - T_0 \ln \frac{T}{T_0} \right]$$

Quality of energy



When gases are flowing in duct at two different section the temp are T_1 & T_2 . the heat lost at higher temp is greater than heat lost at lower temp. this is called as the Quality of energy.

Reversible work in open system exchanging heat with surrounding



on applying the 1st law and 2nd law to the system we can get the maximum amount of work possible

$$dw_{max} = dm_1 \left[h_1 - T_0 s_1 + \frac{v_1^2}{2} + g z_1 \right] -$$

$$dm_2 \left[h_2 - T_0 s_2 + \frac{v_2^2}{2} + g z_2 \right] -$$

$$d \left[U - T_0 S + \frac{mv^2}{2} + mgz \right]$$

for steady flow process:

$$dm_1 = dm_2 = dm$$

$$d \left(U - T_0 S + \frac{mv^2}{2} + mgz \right) = 0$$

$$dw_{max} = dm \left[(h_1 - h_2) - T_0 (s_1 - s_2) + \frac{v_1^2 - v_2^2}{2} + g(z_1 - z_2) \right]$$

$h - T_0 s$ = Keenan function

$$= dm \left[(b_1 - b_2) + \frac{v_1^2 - v_2^2}{2} + g(z_1 - z_2) \right]$$

$$= \left(B_1 + \frac{mv_1^2}{2} + mgz_1 \right) - \left(B_2 + \frac{mv_2^2}{2} + mgz_2 \right)$$

$$\psi = B + \frac{mv^2}{2} + mgz$$

$$\psi_1 - \psi_2 = (B_1 - B_2) + m \left(\frac{v_1^2 - v_2^2}{2} \right) + m(z_1 - z_2)g$$

when K.E = P.E = 0

$$\psi_1 - \psi_2 = B_1 - B_2$$

closed

dw_{max}

dw_{max}

if K.E

dw_{max}

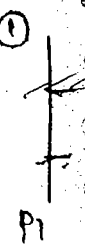
GUDY

IT =

Heat in



heat in
is equ



but with

closed system

$$dm_1 = dm_2 = 0$$

$$dW_{\max} = -d \left[U - T_0 S + \frac{mv^2}{2} + mgz \right]$$

$$= -d [E - T_0 S]$$

$$dW_{\max} = (E_1 - E_2) - T_0 (S_1 - S_2)$$

$$\text{if } KE, PE = 0$$

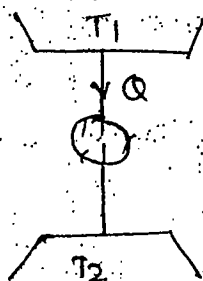
$$dW_{\max} = (U_1 - U_2) - T_0 (S_1 - S_2)$$

system possible

GUDY - STODALA Equation

$$IT_0 = T_0 (ds)_{\text{universe}} = T_0 S_{\text{gen}} + T_0 S_{\text{production}}$$

Heat transferred through finite temp difference



when heat is transferred from high to low its must a loss of available energy as no work is done and

work loss = Carnot work

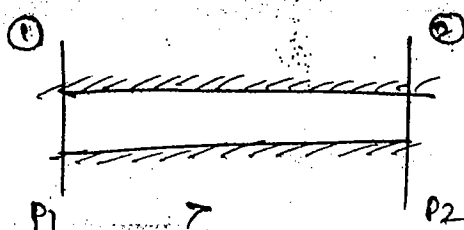
$$W_L = W_C = \frac{Q(T_1 - T_2)}{T_1}$$

$$(S_2 - S_1) - \int \frac{dQ}{T} = S_{\text{gen}}$$

$$\frac{Q}{T_2} - \frac{Q}{T_1} = Q \left(\frac{T_1 - T_2}{T_1 T_2} \right) = S_{\text{gen}}$$

$$I = W_{\text{lost}} = T_2 \cdot S_{\text{gen}}$$

heat fin transfer through finite temp difference is equal to destruction of its availability



$$\Delta P = (P_1 - P_2)$$

$$W_{\text{lost}} = T_0 S_{\text{gen}} = m R T_0 \frac{dP}{P_1}$$

$z_2) g$

Efficiency IInd Law

It is defined Ratio of change in available energy of system to change in available energy of source.

$$ds_1 = \frac{Q}{T_1}$$

$$ds_2 = \frac{Q}{T_2}$$

Efficiency IInd Law for compressor

$$\eta_{\text{IInd law compressor}} = \frac{B_2 - B_1}{W} = \frac{(h_2 - h_1) - T_0(s_2 - s_1)}{W}$$

Efficiency IInd Law for turbine

$$\eta_{\text{IInd law turbine}} = \frac{W}{B_1 - B_2} = \frac{W}{(h_1 - h_2) - T_0(s_1 - s_2)}$$

Efficiency IInd Law for engine

$$\eta_{\text{engine}} = \frac{\eta_{\text{Actual}}}{\eta_{\text{Carnot}}}$$

Efficiency IInd Law, Refrigerator Heat pump

$$\eta_{\text{IInd law Ref. H.P.}} = \frac{(C.O.P.)_{\text{Actual}}}{(C.O.P.)_{\text{Carnot}}}$$

loss in

Qu. 10

$$T_2 = 400$$

$$AE = Q$$

Qu. 11

Qu. 12

pg. No 23 Qu. 9

able energy
by of source.

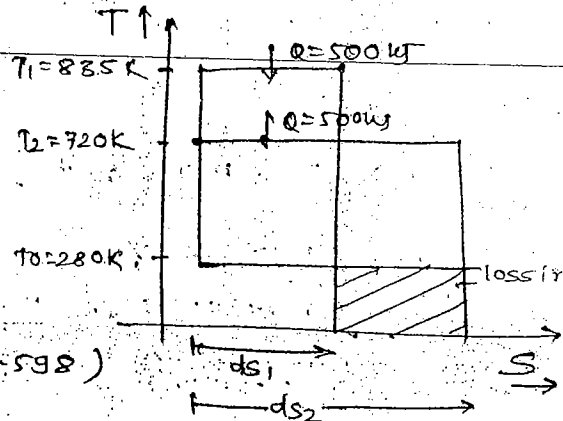
$$ds_1 = \frac{Q}{T_1} = \frac{500}{835} = 0.598$$

$$ds_2 = \frac{Q}{T_2} = \frac{500}{720} = 0.694$$

$$\text{loss in AE} = T_0 (S_2 - S_1)$$

$$= 280 (0.694 - 0.598)$$

$$= 26.88 \text{ kJ}$$



Qu. 10 $m = 1000 \text{ kg}$, $C_p = 0.5 \text{ kJ/kg K}$, $T_1 = 1200 \text{ K}$, $T_0 = 300 \text{ K}$.

$T_2 = 400 \text{ K}$ is kept

$$AE = Q - T_0 dS = m C_p (T_1 - T_2) - m C_p T_0 \ln \frac{T_1}{T_2}$$

$$= 1000 \times 0.5 (1200 - 400) - 1000 \times 0.5 \times 300 \times \ln \frac{1200}{400}$$

$$= 400 \times 10^3 - 549.306 \times 300$$

$$= 235.20 \times 10^3 \text{ kJ}$$

Qu. 11:

$$WU = [u_1 + p_0 v_1 - T_0 s_1] - [u_2 + p_0 v_2 - T_0 s_2]$$

$$= [(h_1 - p_1 v_1) + p_0 v_1 - T_0 s_1] - [(h_2 - p_2 v_2) + p_0 v_2 - T_0 s_2]$$

$$= (2993.5 - 3000 \times 0.08114) + 100 \times 0.08114 - 300 \times 6.1$$

$$- [2706.7 - 200 \times 0.8857 - 300 \times 7.7271] + 100 \times 0.8857$$

$$= \underline{\hspace{2cm}}$$

Qu. 12:

$$I = T_0 S_{\text{gen}}$$

$$= T_0 m R \frac{\Delta p}{P_1}$$

$$= 300 \times 3 \times 200 \times \frac{0.1 P_1}{P_1}$$

$$= 300 \times 3 \times 0.1$$

$$= 25.83$$

$$m = 3 \text{ kg/sec}$$

$$T_0 = 300 \text{ K}$$

$$R = 0.287$$

$$\Delta p = 0.1 P_1$$

Qu. 8 $T_0 = 298 \text{ K} = T_2$

$AE_1 = Q - T_0 \Delta S$

$= m_{cp} (T_1 - T_2) - m_{cp} (T_0) \ln \frac{T_1}{T_2}$

$= \frac{5000}{3600} \times 1 (1273 - 298) - \frac{5000}{3600} \times 1 \times 298 \ln \frac{1273}{298}$

$= 7531 + 1 \underline{7531.60}$

Ind case: hot gases are used to heat up the air upto a temp of 800°C and hot gases are used to run the engine

Heat gained by air = heat lost by hot gases.

$\dot{m}_a c_{p,air} (T_1 - T_2) = \dot{m}_s c_{p,s} (T_1 - T_2)$

$\dot{m}_a 1 (573 - 298) = \frac{5000}{3600} \times 1 (1273 - 298)$

$\dot{m}_a = \underline{4.9242 \text{ kg}}$

$AE_2 = \dot{m}_a c_{p,a} (T_3 - T_2) - \dot{m}_a c_{p,a} \cdot T_0 \ln \frac{T_3}{T_2}$

$= 4.92 \times 1 \times (573 - 298) - 4.93 \times 1 \times 298 \ln \frac{573}{298}$

$= 394.4 \text{ kW}$

loss in AE = $7531 - 394.4 = \underline{358.7}$

Qu. 7: 1st case

$AE_1 = \psi_1 - \psi_0$

$T_1 = 1273 \text{ K}$

$E \rightarrow W$

$T_2 = 298 \text{ K}$

$AE = \psi_1$

Ind case

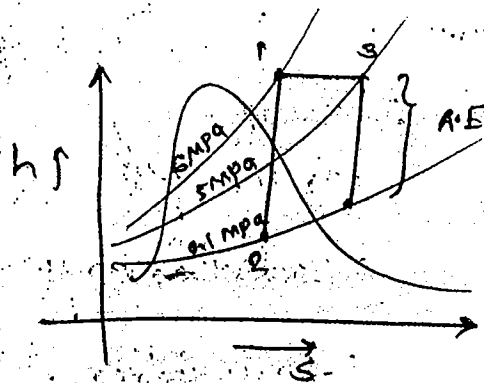
$= (315)$

loss in A

Qu. 6

$\eta_{Dn \text{ low } 10}$

Qu. 9:



$$AE = \varphi_1 - \varphi_0 = (h_1 - h_0) - T_0(S_1 - S_0) = (3177.2 - 83.96) - 293(6.5408 - 0.2966)$$

1263

IIIrd case: $AE_2 = \varphi_3 - \varphi_0 = (h_3 - h_0) - T_0(S_3 - S_0)$

$$= (3177.2 - 83.96) - 293(6.63 - 0.2966) = 1237.5$$

loss in AE = $AE_1 - AE_2$

$$= 1263 - 1237.5$$

$$= \underline{\underline{25.5 \text{ kJ}}}$$

air upto
d to run

3k

$T_0 = 298K$

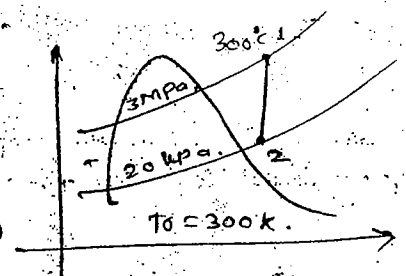
Qu-6:

$$\eta_{\text{max low law (Carnot)}} = \frac{h_1 - h_2}{(h_1 - h_2) - T_0(S_1 - S_2)}$$

$$= \frac{2993.5 - 2609.7}{2993.5 - 2609.7 - 300(6.529 - 7.9085)}$$

$$= \frac{383.8}{383.8 - (-410.85)}$$

$$= \underline{\underline{0.4829}}$$



Qu-9:

$T_0 = 298K$

$T_1 = 1273K$
 $m = 5000 \text{ kg}$

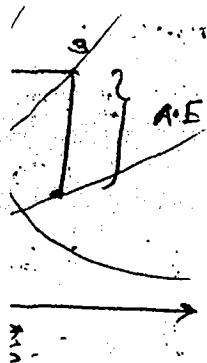
$T_2 = 873K$
 $m = 5000 \text{ kg}$

$$T_3 = \frac{T_1 + T_2}{2} = \frac{1273 + 873}{2} = 1073 \text{ K}$$

$m = 10,000 \text{ kg}$

E

$T_4 = 313K$



$$AE_1 = mcp(T_3 - T_4) - mcp T_0 \ln \frac{T_3}{T_4}$$

$$= 10,000 \times 1 (1073 - 313) - 10,000 \times 1 \times 298 \ln \left(\frac{1073}{313} \right)$$

$$= \underline{3.92 \times 10^8} = 3928.608 \text{ kJ}$$

$$T_1 = 1273 \text{ K}$$

$$5000 \text{ kg}$$

$$T_0 = 298 \text{ K}$$

$$T_4 = 313 \text{ K}$$

$$T_2 = 873 \text{ K}$$

$$5000 \text{ kg}$$

$$T_0 = 298 \text{ K}$$

$$T_4 = 313 \text{ K}$$

$$AE_1 = mcp(T_1 - T_4) - mcp T_0 \ln \frac{T_1}{T_4}$$

$$= 5000 \times 1 \times (1273 - 313) - 5000 \times 1 \ln \frac{1273}{313} \times 298$$

$$= 2.709 \times 10^6$$

$$AE_2 = mcp(T_2 - T_4) - mcp T_0 \ln \frac{T_2}{T_4}$$

$$= 5000 \times 1 \times (873 - 313) - 5000 \times 1 \ln \frac{873}{313} \times 298$$

$$= 1.271 \times 10^6$$

$$AE = AE_1 + AE_2$$

$$= \underline{3.98 \times 10^6}$$

It is given

$$AE_1 - AE$$

$$\text{loss of } AE = 3928.608 - 3.98 \times 10^6$$

Q4.3

$$m = 100 \text{ kg}$$

$$AE = mcp(T - T_0) - mcp T_0 \ln \frac{T}{T_0}$$

$$= 100 \times 4.187 (90 - 0) - 100 \times 4.187 \times 273 \ln \frac{363}{273}$$

$$= \underline{5113.929 \text{ kJ}}$$

73
13

Q.1

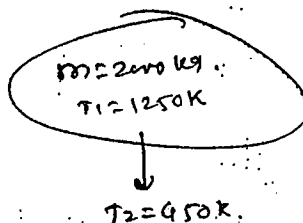
$$\boxed{P_1 = 1 \text{ MPa} \rightarrow P_2 = 0.1 \text{ MPa}} \\ \boxed{T_1 = 300 \text{ K} \quad T_0 = 300 \text{ K}}$$

$$\begin{aligned} W &= U_1 - U_2 - T_0(S_1 - S_2) \\ &= -T_0(S_1 - S_2) \\ &= T_0(S_2 - S_1) \\ &= 300 \times 8.314 \ln \frac{P_1}{P_2} \\ &= 300 \times 8.314 \ln \left(\frac{1}{0.1} \right) \\ &= \underline{5743.107 \text{ kJ}} \end{aligned}$$

Ans = 5743.107 kJ

Ans 3.

Pg. 50 Q.1.7

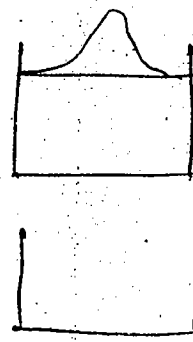


$$C_p = 0.5 \\ T_0 = 303 \text{ K}$$

$$\begin{aligned} AE &= m c_p (T_1 - T_2) - m c_p (T_0 \ln \frac{T_1}{T_2}) \\ &= 2000 \times 0.5 (1250 - 450) - 2000 \times 0.5 \times 303 \ln \left(\frac{1250}{303} \right) \end{aligned}$$

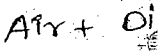
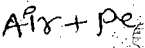
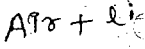
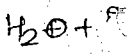
Pg. 54 Q.2.1

$$\begin{aligned} K_{\text{Useful}} &= K_1 - K_{\text{loss}} \\ &= P_{\text{dr}} - P_{\text{odv}} \\ &= 300 \times 0.1 - 100 \times 0.01 \\ &= \underline{29 \text{ W}} \end{aligned}$$



$$\ln \frac{363}{273}$$

pure &
is, chem
phase.
water



Vapor

Every
a par
Satur
temp

P_{sa}

T_{sa}

P_{sa}

Dryne

drynes

properties of pure substance

pure substance is homogeneous in composition invariant in chemical aggregation. it may exist in more than one phase:

water is a pure substance, ice is a pure substance
 $H_2O + ice + vapor \rightarrow$ pure substances

Air + liquid $\rightarrow$ Not a pure substance

Air + petrol vapor $\rightarrow$ is a pure substance

Air + Diesel vapor $\rightarrow$ not a pure substance

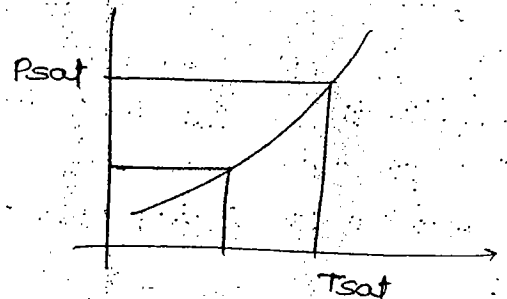
Vapor pressure curve

Every liquid boils at a particular temp corresponding a particular pressure the pressure is called as saturation pressure & temp is called as saturation temp.

$$P_{sat} \Rightarrow T_{sat}$$

$$T_{sat} \Rightarrow P_{sat}$$

$$P_{sat} \Rightarrow T_{sat}$$



Dryness fraction x

$$\text{Dryness fraction } x = \frac{\text{mass of vapor}}{\text{mass of vapor} + \text{mass of liquid}}$$

$$= \frac{m_v}{m_v + m_l}$$

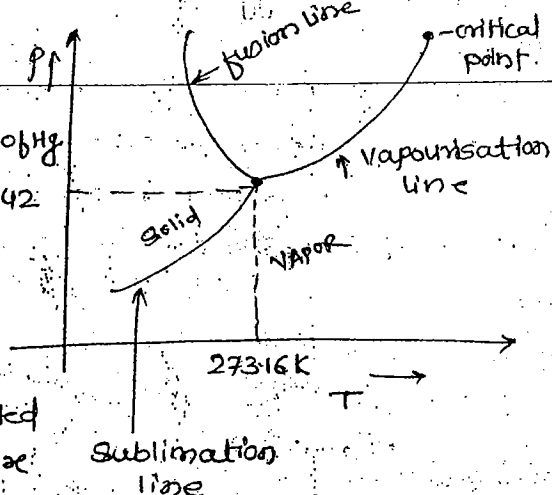
$$= \frac{1}{1 + \frac{m_l}{m_v}}$$

$$\boxed{\frac{m_l}{m_v} = \frac{1-x}{x}}$$

Every substance has a triple point of its own.
triple point is a point which exist as a solid, liquid and vapor.

Sublimation & vapor line

having +ve slope 4.58 mm of Hg
where as fusion line 610.42
having -ve slope
this is due to anomalous expansion of water



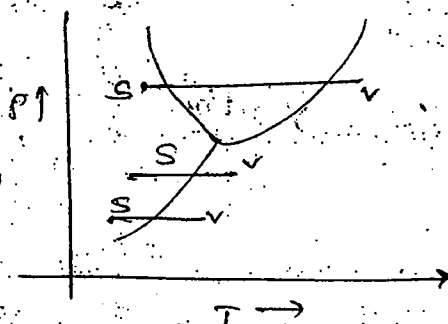
Any substance is heated below its triple point pressure solid become a vapor.

and process is called sublimation.

Any substance cooled below the triple point pressure vapor becomes a solid and the principle is called ablimation

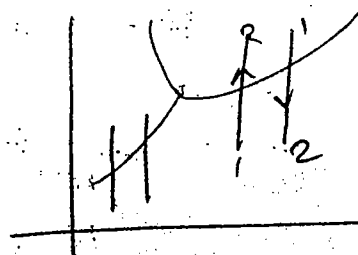
Any substance is heated above its triple point solid become liquid, liquid becomes a vapor

Isothermal compression of liquid beyond the triple point temp. convert a vapor to liquid. isothermal expansion of liquid beyond its triple point temp. convert a liquid to vapor



isothermal compression of liquid less than the triple point temp convert a vapor to solid form.

Isothermal expansion liquid less than the triple point of temp. convert solid to vapor form



A pure substance
Degree of freedom

$$F =$$

How many

$$p = 3$$

$$F =$$

How many

$$F =$$

$$F =$$

only 1
fusion
where
fusion
 $p = 0$

Gibbs phase rule

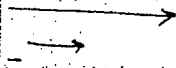
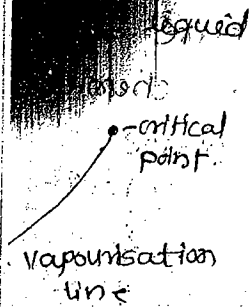
" It state that

$$P + F = C + 2$$

C = No. of component

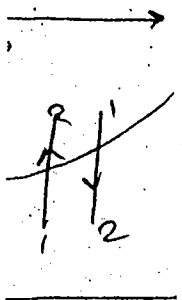
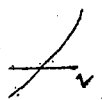
F = Degree of freedom

P = No. of phases



point

triple point
or



A pure substance always says a single component substance F represent no. of degree of freedom Degree of freedom means the no. of independent coordinate required to specify the state of system

$$F = C + 2 - P$$

How many D.O.F are there at triple point of H_2O

$$P = 3, C = 1$$

$$F = 1 + 2 - 3 = 0$$

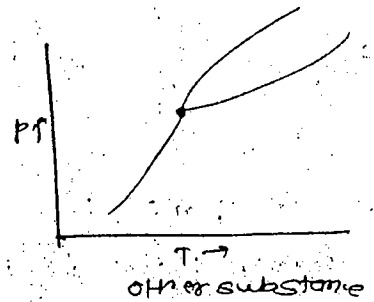
How many D.O.F at liquid vapor separation line

$$F = C + 2 - P \quad C = 1 \quad P = 2$$

$$F = 1$$

only for H_2O , Antimony and Bismuth the fusion line is having 've' slope where as for all the remaining substance the fusion line having '+ve' slope.

$$P = 2$$



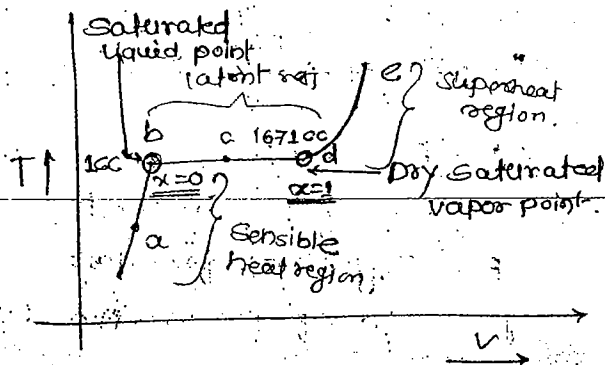
$P = C$

$H_2O \quad T_1 = 0^\circ C$

$H_2O \quad T_2 = 100^\circ C$

Steam $T_2 = 100^\circ C$

Steam $T_3 > 100^\circ C$



This is $a \Rightarrow$ subcooled state / compressed liquid state in this $T_a < T_{sat}$

$$\text{Degree of Subcooling} = T_{sat} - T_a$$

$b \Rightarrow$ Saturated liquid state

this is maximum point at which liquid is in liquid form and this point onward the liquid start getting converted to vapor. that is the $x=0$

$c \Rightarrow$ Here it is partly the form liquid & partly the form of vapor. liquid proportion having liquid properties and vapor portion having vapor properties. $0 < x < 1$

$d \Rightarrow$ here completely vapor state and $x=1$ no water. mass of liquid is zero.

$e \Rightarrow$ Superheated vapor state. here $T_e > T_{sat}$

$$\text{Degree of Superheat} = T_e - T_{sat}$$

In the liquid region when heat is supplied if temp changes it is called as sensible heating region. when heat is supply temp does not change it is called as latent heat.

In the Superheated region when heat is supplied temp is change it is called as Superheat region.

o family

The loc
Saturat
called c.
line.

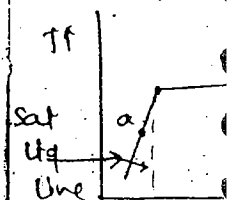
the
dry sat
called
vapor

The criti
change
critical
point
heat is

$$\left(\frac{\partial}{\partial} \right)$$

$$\left(\frac{\partial}{\partial} \right)$$

As
heat of



enthalpy h_f $\frac{h_{g-f}}{v_{g-f}}$

of $\frac{q_{g-f}}{v_{g-f}}$

$\frac{v}{v_g}$

Subcooled region.
dry saturated vapor point.

→
→
used liquid state

is in liquid
line $x=0$

partly
mixing
vapor

$x=1$

$T > T_{sat}$

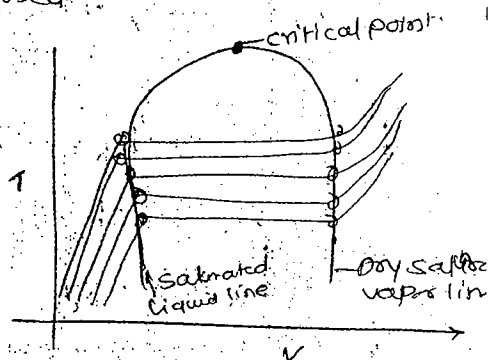
if
g regions
region it is

region
is called as

If the experiment is repeated at different pressure a family of curves is obtained.

The locus of all the Saturated liquid point is called as Saturated liquid line.

The locus of all the dry saturated vapor point is called as dry saturated vapor line.

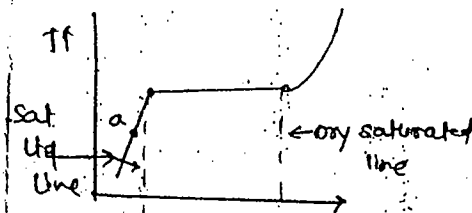


Both this line meet at critical point. The critical point is the point at which the curve change its slope from +ve to -ve. critical point is called as zero slope point or point of inflection. at zero slope point latent heat is zero.

$$\left(\frac{\partial p}{\partial v} \right)_{T=T_{critical}} = 0$$

$$\left(\frac{\partial^2 p}{\partial v^2} \right)_{T=T_{critical}} = 0$$

As the pressure goes on increasing the latent heat of steam goes on decreasing.



$$h_g - h_f = h_{fg} = L$$

$$s_g - s_f = s_{fg}$$

$$v_g - v_f = v_{fg}$$

$$v_g - v_f = v_{fg}$$

$$v_f \ll v_g$$

a = subcooled state

$$h_a = h_f + c_{p_l}(T_{sat} - T_a)$$

$$s_a = s_f + c_{p_l} \ln \frac{T_{sat}}{T_a}$$

Corresponding to temp T_a whatever are the h_f & h_a values are same as the calculated values.

$c \Rightarrow$ liquid + vapor state
 here it is partly in form of liquid partly form of vapor.

on a p
 like a
 like a l

$$h_c = (1-x)h_f + xh_g$$

$$= h_f + x(h_g - h_f)$$

$$= h_f + xh_{fg}$$

$$\boxed{h_c = h_f + xh_{fg}}$$

$$s_c = (1-x)s_f + xs_g$$

$$= s_f + x(s_g - s_f)$$

$$\boxed{s_c = s_f + xs_{fg}}$$

$$v_c = (1-x)v_f + xv_g$$

$$= v_f + x(v_g - v_f)$$

$$v_c = v_f + xv_{fg} \quad \text{but } v_f \ll v_g$$

$$\boxed{v_c = xv_g}$$

$e \Rightarrow$ superheated vapor state

$$T_e > T_{sat}$$

$$h_e = h_g + c_{p,v}(T_e - T_{sat})$$

$$s_e = s_g + c_{p,v} \ln \frac{T_e}{T_{sat}}$$

$$\boxed{\frac{v_e}{v_g} = \frac{T_e}{T_{sat}}}$$

$$\boxed{s_g - s_f = \frac{h_g - h_f}{T_{sat}}}$$

$$\boxed{s_g - s_f = \frac{\text{Latent heat}}{T_{sat}}}$$

Temp

-5°C

$\downarrow$

0°C

$\downarrow$

0°C

$\downarrow$

100°C

$\downarrow$

100°C

$\downarrow$

1100°C

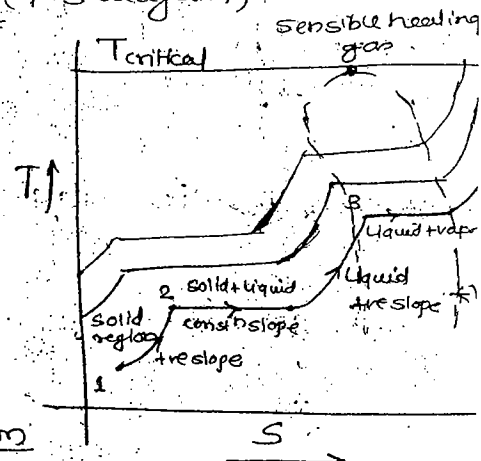
In the
 two ph
 critical
 close and
 the mole
 dry satu
 is called
 approxi
 separate
 is not a
 approxi

only form

on a pressure temp plane the triple point is like a point. on a PV plane the triple point is like a line on a UV plane it is like a plane

Temp-Entropy diagram (T-s diagram)

-5°C	T ₁ ice	$ds_1 = c_{p,ice} \ln \frac{T_2}{T_1}$
↓		
0°C	T ₂ ice	$ds_2 = \frac{L_{ice}}{T_2}$
↓		
0°C	T ₂ H ₂ O	$ds_3 = c_{p,w} \ln \frac{T_3}{T_2}$
↓		
100°C	T ₃ H ₂ O	$ds_4 = \frac{\text{Latent heat steam}}{T_4}$
↓		
100°C	T ₄ steam	$ds_5 = c_{p,steam} \ln \frac{T_5}{T_4}$
↓		
700°C	T ₅ steam	



In the single phase region the slope are free. In two phase region the slope are constant. beyond critical temp it is called as superheated gas. gas laws are exactly followed in this region because the molecular separation is very high. between dry saturated vapor line and critical temp line is called as superheated vapor. and gas laws are approximated in this region because molecular separation is not high and ideal gas behaviour is not exactly followed in this region but it is approximated.

Latent heat, enthalpy
T_{Sat}

h-s diagram / mollier diagram

$$Tds = dh - vdp$$

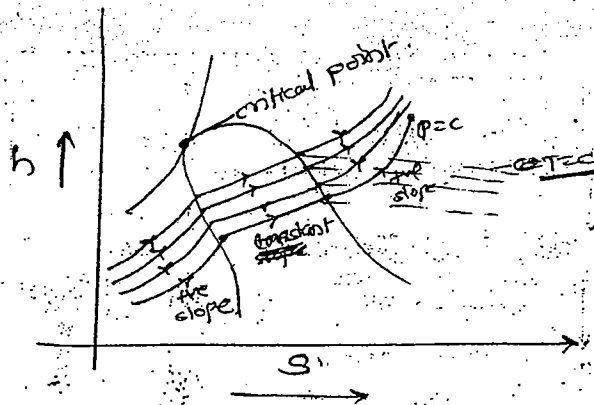
if $p = c \quad dp = 0$

$$Tds = dh$$

$$\frac{dh}{ds} = T$$

** slope of mollier diagram is equal to its temperature

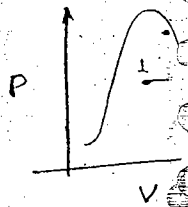
H_2O T_1 $0^\circ C$
 $\downarrow$
 H_2O T_2 $100^\circ C$
 $\downarrow$
 Steam T_2 $100^\circ C$
 $\downarrow$
 steam $T_3 > 100^\circ C$



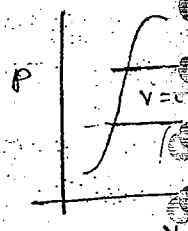
The constant pressure line are closed spaced in the liquid region where as constant pressure lines are divergent in the superheated region. The constant temp line are dropping line in the superheated region.

1) The line in hyperbola

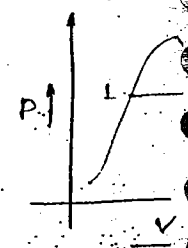
$$p = c$$



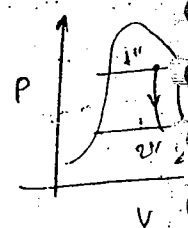
$$v = c$$



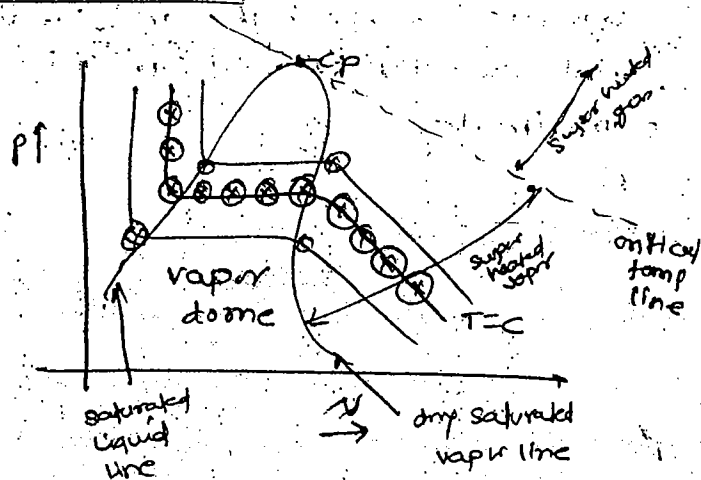
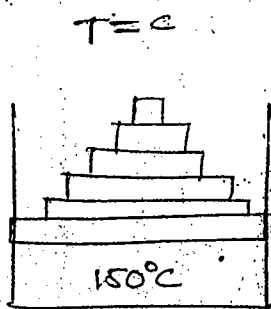
$$T = c$$



$$S = c$$



p-v diagram or isothermal



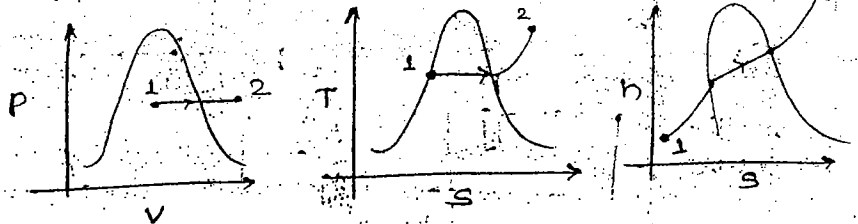
for det be cold

- ①
- ②
- ③

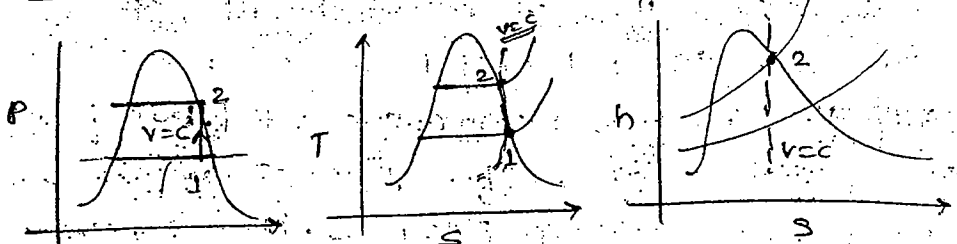
In the vapor dome isothermal line is horizontal line. In the superheated region it is a rectangle hyperbola

Temperature

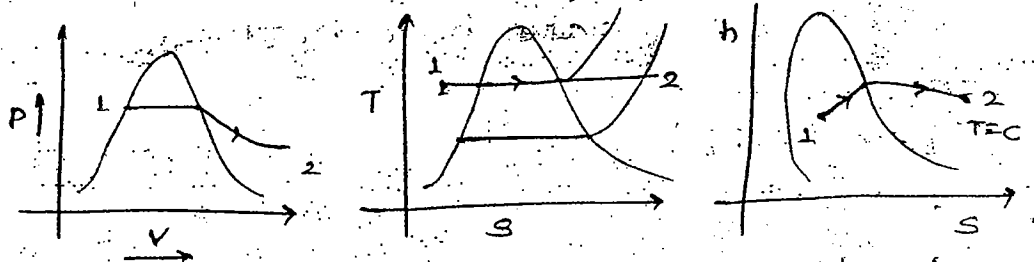
$p=c$ Isobaric



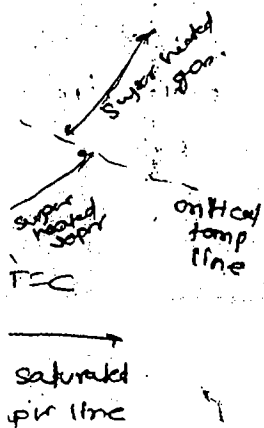
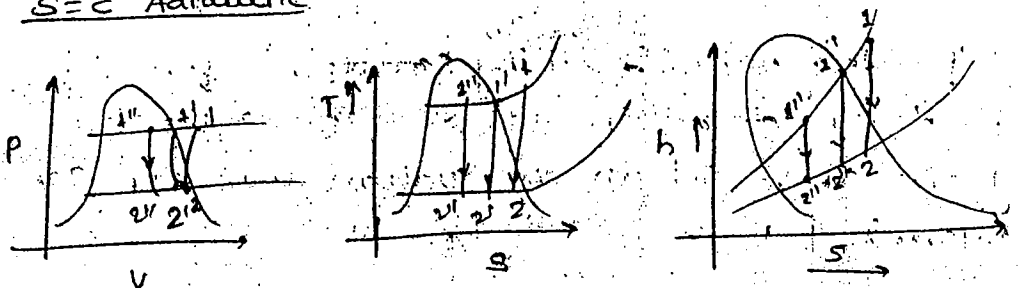
$v=c$ Isochoric



$T=c$ Isothermal



$S=c$ Adiabatic

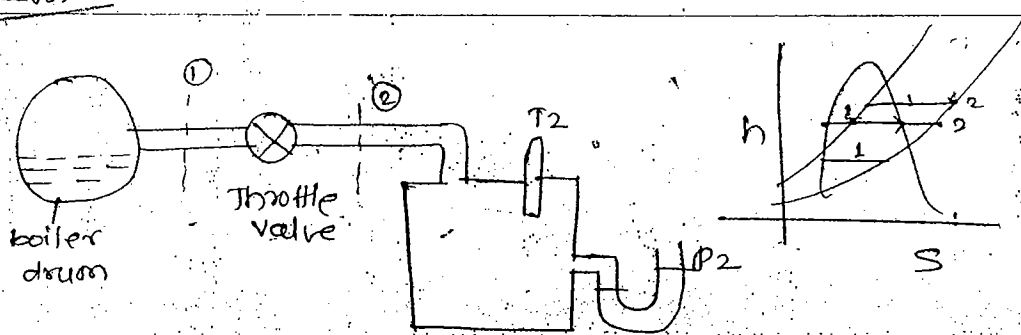


for determining the dryness fraction of steam we will be using different methods

- ① Throttling calorimeter
- ② Separating & Throttling calorimeter
- ③ electrical calorimeter

using any one of the above the dryness fraction can be determined. Throttling calorimeter is used for determining the dryness fraction of high quality steam.

used:



In this method the steam is throttled to a higher pressure to a lower pressure. after throttling the temp & pressure are noted. but for good results the degree of superheat after throttling must be atleast 5 to 10°C . knowing the pressure and knowing the temp from the superheat table the enthalpy h_2 is calculated. before throttling the steam is in wet ~~state~~ ^{state} hence $h_2 = h_1$.

$$h_2 = h_1$$

$$= h_{f1} + x(h_{g1} - h_{f1})$$

$$x = \frac{h_2 - h_{f1}}{h_{g1} - h_{f1}}$$

for minimum ^{quality} throttling condition after throttling steam should dry and saturated using the above set up any quality above x_1 can be determined by this method. quality above 90% can be determined by the above set up by throttling method.

dryness in

In the steam is quality x After h_1 and from calculate

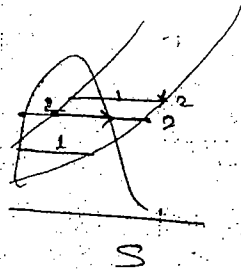
pressure are not calculated

$$h_2 = h_1$$

x_1

mass of

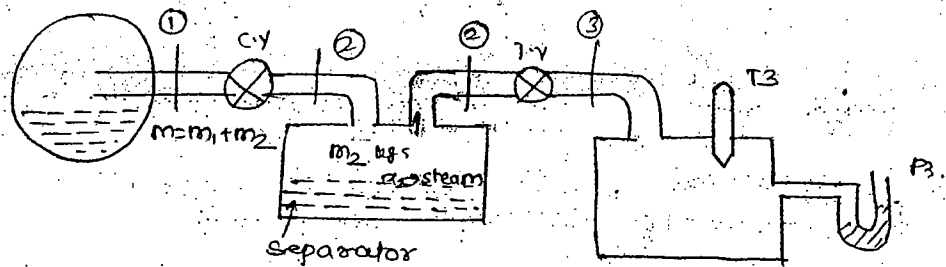
is fraction
is used for
quality



d to a
for
but for
for
along the
superheat
- throttling
or

for
rated
x₂ can
be got
by

For low quality steam separating and throttling calorimeter
used.



mass of
water = m_1 kgs.

$$\text{Dryness fraction in separator} = \frac{\text{mass of steam}}{\text{total mass}}$$

$$= \frac{m_2}{m_1 + m_2}$$

In the Separator water is separated and low quality steam is converted to high quality steam and high quality steam is throttled to higher pressure to lower pressure.

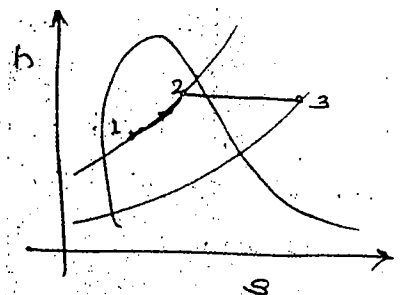
After throttling the pressure and temp are measured and from superheat tables the enthalpy h_3 can be calculated.

After throttling the pressure at P_3 and temp T_3 are noted from which enthalpy calculated.

$$h_3 = h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

$$x_2 = \frac{h_3 - h_{f2}}{h_{g2} - h_{f2}}$$

$$\text{mass of vapor} = x_2 m_2$$



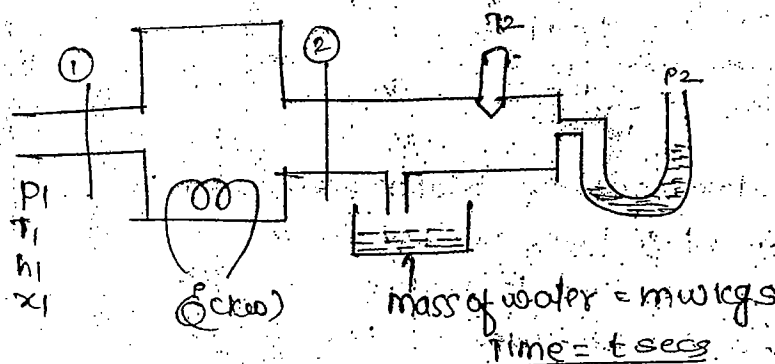
wherever is the mass of vapor in the final stage is nothing but mass of vapor generated in the boiler

Dryness fraction in steam of boiler = x

$$x = \frac{\text{mass of vapor}}{\text{total mass}} = \frac{x_2 m_2}{m_1 + m_2}$$

$$x = x_2 x_1$$

Electrical calorimeter



$$\text{mass flow rate} = \dot{m} = \frac{m_w}{t} \text{ (kg/sec)}$$

The steam flowing is heated by means of heater afterwards the pressure P_2 and temp T_2 are noted and pressure P_2 and temp T_2 enthalpy h_2 is calculated

Apply SFEE

$$\dot{m}h_1 + \dot{Q} = \dot{m}h_2 + \dot{W}$$

$$h_1 = h_2 - \frac{\dot{Q}}{\dot{W}}$$

$$h_{f1} + x(h_{s1} - h_{f1}) = h_2 - \frac{\dot{Q}}{\dot{m}}$$

$$x = \frac{(h_2 - \frac{\dot{Q}}{\dot{m}}) - h_{f1}}{(h_{s1} - h_{f1})}$$

various

Non-fl

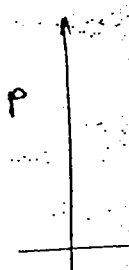
Isot



Isot



Hyper



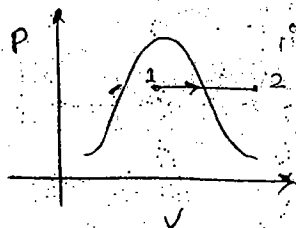
generate in

Various processes involving steam

Non-flow process

Isobaric :

$$P_1 = P_2 = P$$



$$1Q_2 - 1W_2 = 1U_2$$

$$1Q_2 = 1W_2 + 1U_2$$

$$= P_2(V_2 - P_1) + 1U_2$$

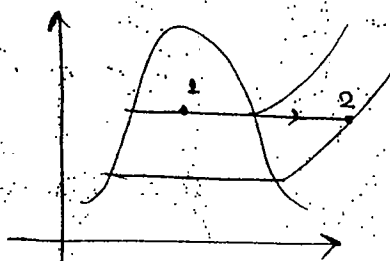
$$= (P_2 V_2 - P_1 V_1) + U_2 - U_1$$

$$= (U_2 + P_2 V_2) - (U_1 + P_1 V_1)$$

$$1Q_2 = (h_2 - h_1)$$

Isothermal process

$$T = C$$

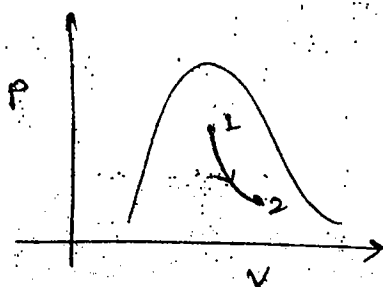


$$1Q_2 - 1W_2 = 1U_2$$

$$1W_2 = 1Q_2 - 1U_2$$

$$1W_2 = T(S_2 - S_1) - (U_2 - U_1)$$

Hyperbolic process



$PV = RT$ eqn is not valid in the vapor dome but

$P_1 V_1 = P_2 V_2$ is valid

$$PV \neq RT$$

$$1Q_2 - 1W_2 = 1U_2$$

$$1Q_2 = (U_2 - U_1) + 1W_2$$

$$= (U_2 - U_1) + P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= [(h_2 - P_2 V_2) - (h_1 - P_1 V_1)] + P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= (h_2 - h_1) + P_1 V_1 \ln \frac{V_2}{V_1}$$

of heater
is 2 are
slpy h_2 is

constant volume process $V=C$ $V_1=V_2$

$$V_1=V_2$$

$$x_1 v g_1 = x_2 v g_2$$

$$1Q_2 - 1W_2 = 1U_2$$

$$1Q_2 = 1U_2 = U_2 - U_1$$

$$= (h_2 - P_2 v_2) - (h_1 - P_1 v_1)$$

$$1Q_2 = (h_2 - h_1) - V(P_2 - P_1)$$

polytropic process

$$p v^n = C$$

$$1Q_2 - 1W_2 = 1U_2$$

$$1Q_2 = (U_2 - U_1) + 1W_2$$

$$= (U_2 - U_1) + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$\left[(h_2 - P_2 v_2) - (h_1 - P_1 v_1) \right] + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$1Q_2 = (h_2 - h_1) + \frac{n}{n-1} (P_1 v_1 - P_2 v_2)$$

Flow process

$$h_1 + Q_1 = h_2 + W$$

constant volume $V=C$

$$V_1 = V_2 = V$$

$$1W_2 = V(P_1 - P_2)$$

$$Q = (h_2 - h_1) + W$$

$$= (h_2 - h_1) + V(P_1 - P_2)$$

$$= (h_2 - P_2 v_2) - (h_1 - P_1 v_1)$$

$$= (U_2 - U_1)$$

constant

Isotherm

Adiabatic

polytropic

$1Q_2$

$1Q_2$

$1U_2$

For a reference for a

steady

triple

h_{triple}

http

constant pressure $W=0$

$$Q = (h_2 - h_1) \text{ kJ/kg}$$

Isothermal process

$$h_1 + Q = h_2 + w$$

$$Q = h_2 - h_1 + w$$

$$Q = (h_2 - h_1) + p v_1 \ln\left(\frac{v_2}{v_1}\right)$$

Adiabatic process

$$Q = 0$$

$$h_1 = h_2 + w$$

$$w = (h_1 - h_2) \text{ kJ/kg}$$

polytropic process

$$p v^n = c$$

$$1Q_2 = 1w_2 + (h_2 - h_1)$$

$$1Q_2 = (p_1 v_1 - p_2 v_2) \frac{n}{n-1} + (h_2 - h_1)$$

$$1Q_2 = \left(\frac{p_1 v_1 - p_2 v_2}{n-1} \right) + (u_2 - u_1)$$

for construction a steam table we require a reference point. what is the reference point for construction a steam table.

A reference point for the constructed steam table is triple point of water at the triple point of water we assume that $u=0$, $s=$

$$h_{\text{triple point (TP)}} = p_{TP} - v_{TP}$$

$$h_{TP} \neq 0$$

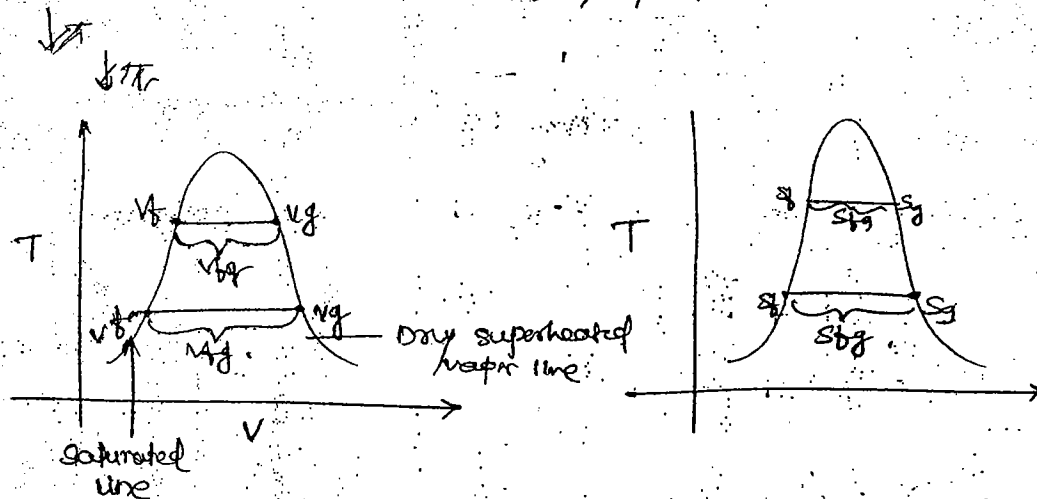
Here Steam tables are used:-

- ① pressure classification
- ② Temp classification
- ③ superheat tables

$$P_{sat} \rightarrow T_{sat}, v_f, v_g, h_f, h_g, h_{fg}, s_f, s_g,$$

$$T_{sat} \rightarrow P_{sat}, P_f, P_g, h_f, h_g, h_{fg}, s_f, s_g.$$

$$P_{sat} \rightarrow T_{sat} \rightarrow T, h, v, s$$



$$P_{sat} \uparrow T_{sat} \uparrow v_f \uparrow v_g \downarrow v_{fg} \downarrow s_f \uparrow s_g \downarrow s_{fg} \downarrow h_f \uparrow$$

h_g increases up to particular value later it starts decreases, and h_{fg} decreases

h_g goes on increasing upto 240°C from 240°C to critical temp h_g values start decreasing.

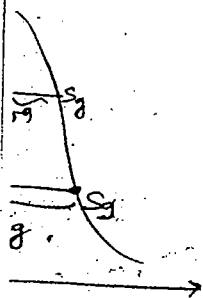
Q.6

For min
throttling
determine

P_1
 T_1
 h_1
 x

Appl

s_g
 s_f



↓ s_g ↓ h_f ↑
 or its
 240°C to
 mg.

pg No 21 ex. 5

$$P_2 = 100 \text{ kPa}$$

$$T_{\text{sat}} = 99.6^\circ\text{C}$$

$$T_2 > T_{\text{sat}}$$

$$100 \text{ kPa } T_2 = 120^\circ\text{C } h_2 = 2716.2 \text{ kJ/kg}$$

$$h_2 = h_1 + x(h_g - h_f)$$

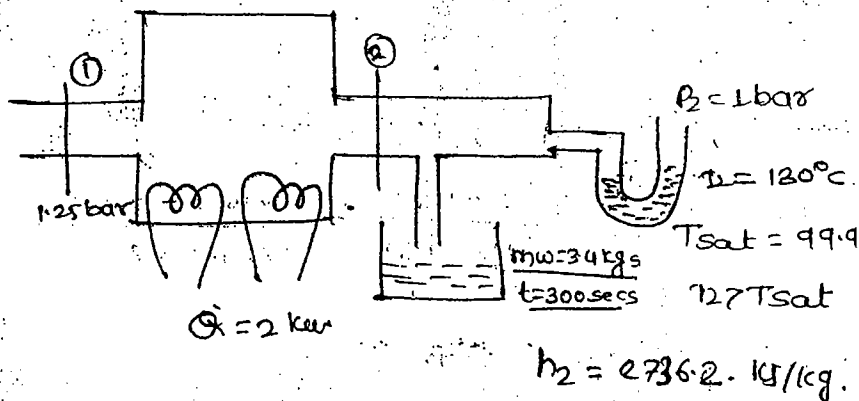
$$2716.2 = 1008.3 + x(2802.3 - 1008.3)$$

$$x = \frac{2716.2 - 1008.3}{2802.3 - 1008.3}$$

$$x = 0.95 \text{ (high quality steam)}$$

For minimum quality condition the enthalpy after throttling. Any quality above minimum quality can be determined using the existing set-up.

ex. 6



Apply SFEE

$$\dot{m}h_1 + \dot{Q} = \dot{m}h_2 + \dot{w}$$

$$h_1 = h_2 - \frac{\dot{Q}}{\dot{m}} = h_{f1} + x(h_{g1} - h_{f1})$$

$$\dot{m} = \frac{m_w}{t} = \frac{3.4}{300} = 0.0113 \text{ kg/sec}$$

$$h_1 = h_2 - \frac{\dot{Q}}{\dot{m}} = 2736.2 - \frac{2}{0.0113}$$

$$= 2559.72 \text{ kJ/kg}$$

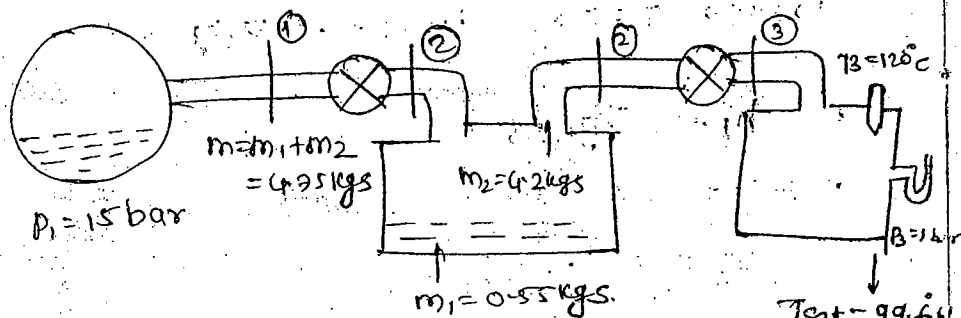
$$h_{f1} + x(h_{g1} - h_{f1}) = h_4$$

$$444.4 + x(2685.2 - 444.4) = 2559.72$$

$$x = 0.944$$

$$x < x_1$$

Q12:

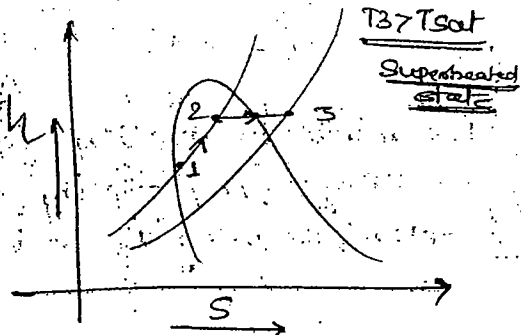


x_1 = dryness fraction in Separator

$$= \frac{m_2}{m_1 + m_2}$$

$$= \frac{4.2}{4.75}$$

$$= 0.884$$



from Superheated table

$$h_3 = 2716.2 \text{ kJ/kg}$$

$$h_{f2} + x_2(h_{g2} - h_{f2}) = h_3$$

$$x_2 = \frac{h_3 - h_{f2}}{h_{g2} - h_{f2}} = \frac{2716.2 - 844.6}{2789.9 - 844.6} = 0.962$$

Mass of vapor = $x_2 m_2$

$$= 0.962 \times 4.2$$

$$= 4.04 \text{ kg/s}$$

Whatever the mass of vapor carry at final stage is nothing but mass of vapor generated in boiler.

$$\text{dryness fraction in boiler} = \frac{m_v}{m_1 + m_2}$$

$$= \frac{4.04}{4.75}$$

$$x = 0.85$$

Mass b

ma

m

5000

Energy

m

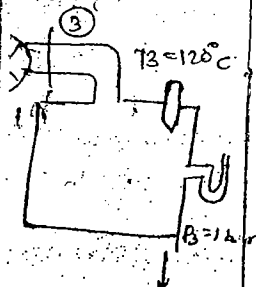
50

$$x = x_1 x_2$$

$$= 0.884 \times 0.962 = 0.85$$

$$x < x_1 < x_2$$

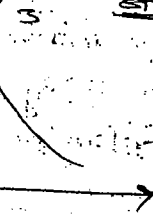
Ques 13



$$T_{sat} = 99.6^\circ\text{C}$$

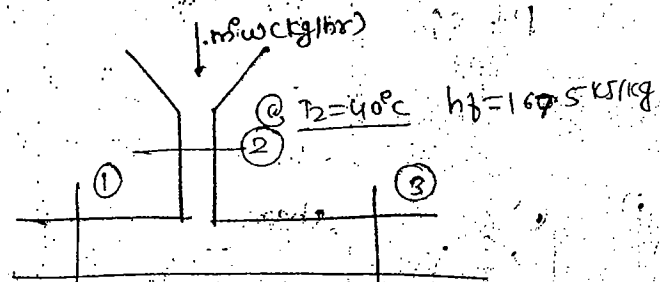
$$T_3 > T_{sat}$$

Superheated state



$$= 0.962$$

2nd stage
in boiler



$$P_1 = 5 \text{ bar}$$

$$T_1 = 300^\circ\text{C}$$

$$T_{sat} = 151.9^\circ\text{C}$$

$T_1 > T_{sat}$ hence it is in superheated state

$$h_1 = 3064.8 \text{ kJ/kg}$$

$$\dot{m}_s = 5000 \text{ kg/hr}$$

$$P_3 = 3 \text{ bar}$$

$$x_3 = 0.95$$

$$h_3 = h_{f3} + x_3(h_{g3} - h_{f3})$$

$$\begin{aligned} h_2 &= h_{f2} + x_3(h_{g3} - h_{f1}) \\ &= 651.4 + 0.95(2724.7 - 651.4) \\ &= 2621 \text{ kJ/kg} \end{aligned}$$

$$\dot{m}_3 = \dot{m}_s + \dot{m}_w$$

Mass balance

mass entering = mass leaving

$$\dot{m}_s + \dot{m}_w = \dot{m}_3$$

$$5000 + \dot{m}_w = \dot{m}_3$$

Energy balance

$$\dot{m}_s h_1 + \dot{m}_w h_{f2} = \dot{m}_3 h_3$$

$$5000 \times 3064.8 + \dot{m}_w \times 167.5 = (5000 + \dot{m}_w) \times 2621$$

$$\dot{m}_w = 904 \text{ kg of water}$$

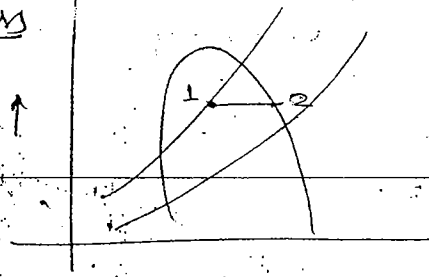
~~XXXX~~

Throttling process

$$h_1 = h_2$$

$$T \downarrow \quad S \uparrow \quad x \uparrow$$

$$P \downarrow \quad v \uparrow$$



$$h_4 = 19$$

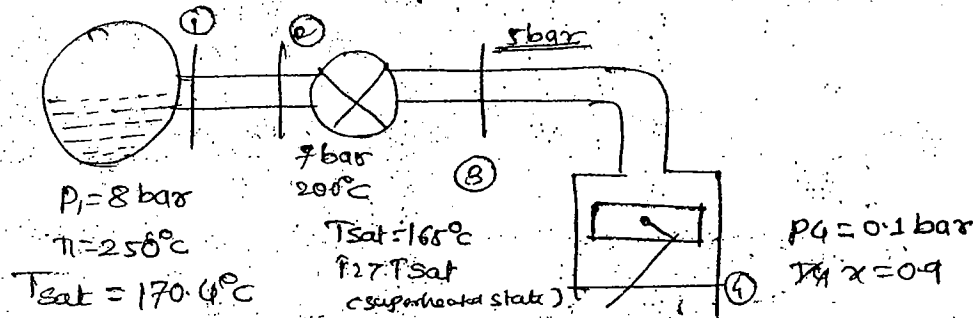
$$= \frac{x}{1-x}$$

$$S_4 = S$$

$$= 0$$

$$= 7$$

Q44:



$$T_2 > T_{\text{sat}} \text{ (superheated state)}$$

$$h_2 = 2844 \text{ kJ/kg}$$

$$S_2 = 6.886 \text{ kJ/kg K}$$

$$h_f = 2930 \text{ kJ/kg}$$

$$S_f = 6.815 \text{ kJ/kg}$$

at 3 at 5 bar

$$T_{\text{sat}} = 151.9^\circ\text{C}$$

$$h_g = 2747.5 \text{ kJ/kg}$$

as it is throttling process $h_2 = h_3$ & $h_3 > h_g$ at 5 bar

$$h_3 = h_g + c_{p, \text{vapor}} (T_3 - T_{\text{sat}})$$

$$2844.2 = 2747.5 + 2.1 (T_3 - 151.9)$$

$$\boxed{T_3 = 197.9^\circ\text{C}}$$

$$S_3 = S_g + c_{p, \text{vapor}} \ln \left(\frac{T_3}{T_{\text{sat}}} \right)$$

$$= 6.819 + 2.1 \ln \left(\frac{273 + 197.9}{273 + 151.9} \right)$$

$$= 7.03 \text{ kJ/kg K}$$

$$h_4 = h_{f4} + x(h_{g4} - h_{f4})$$

Apply

$$h_1$$

heat loss

Temp d.

Work out

$$h_1$$

entropy

$$(S_3$$

entropy

$$(S_4 - S_3)$$

$$h_4 = 191.8 + 0.9(2524.8 - 191.8)$$

$$= \underline{2345.5}$$

$$S_4 = S_{f4} + x(S_{g4} - S_{f4})$$

$$= 0.649 + 0.9(8.151 - 0.649)$$

$$= 7.4 \text{ kJ/kg}$$

Apply STEE : pipe line $w_{\text{pipe}} = 0$

$$h_1 + Q_p = h_2 + w$$

$$Q_p = (h_2 - h_1)$$

$$= 2844 - 2930$$

$$= -86 \text{ kJ/kg}$$

heat loss

$$= 0.1 \text{ bar}$$

$$x = 0.9$$

$$\text{Temp drop} = (T_2 - T_3) = 200 - 197.9 = \underline{2.1^\circ\text{C}}$$

Work out of engine we assume $Q = 0$

$$h_3 + Q = h_4 + w$$

$$w = h_3 - h_4$$

$$= 2844 - 2345.5$$

$$= \underline{498.5 \text{ kJ/kg}}$$

5 bar

entropy change in throttle valve = $(S_3 - S_2)$

$$(S_3 - S_2) = 7.03 - 6.886 = \underline{0.144}$$

entropy change in engine = $(S_4 - S_3)$

$$(S_4 - S_3) = (7.4 - 7.03)$$

$$= \underline{0.37}$$

Q1.4

$$P_2 = 700 \text{ kPa}$$

$$T_2 = 400^\circ \text{C}$$

$$h_2 = 3269 \text{ kJ/kg}$$

$$v_2 = 0.44 \text{ m}^3/\text{kg}$$

$$u_2 = h_2 - P_2 v_2$$

$$= 3269 - 700 \times 0.44$$

$$= 2961 \text{ kJ/kg}$$

$$\text{Work} = P(v_2 - v_1)$$

$$= 700 (0.44 - 0.371)$$

$$= 48.3 \text{ kJ/kg}$$

$$u_1 + Q = u_2 + w_s - w_p$$

$$Q = (u_2 - u_1) + (w_s - w_p)$$

$$0 = u_2 (2961 - 2799.3) + 48.3 - w_p$$

$$w_p = +210 \text{ kJ/kg}$$

$$\Delta h = (h_2 - h_1)$$

$$= (3269 - 3059) = 210$$

$$\Delta u = u_2 - u_1 = 2961 - 2799.3 = 161.7$$

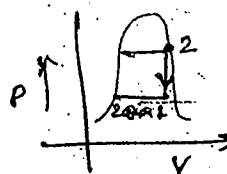
Q1.7 Pg No: 28

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

$$m = 5 \text{ kg}$$

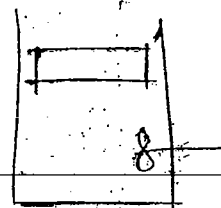
$$P = 200 \text{ kPa}$$

$$\text{sp vol } v = \frac{\text{volume}}{\text{mass}} = \frac{3}{5} = 0.6 \text{ m}^3/\text{kg}$$



$$v_{g1} = 0.885 \frac{\text{m}^3}{\text{kg}}$$

$$2742.7 - h$$



$$P_1 = 700 \text{ kPa}$$

$$T_1 = 300^\circ \text{C}$$

$$h_1 = 3059$$

$$v_1 = 0.371$$

$$u_1 = h_1 - P_1 v_1$$

$$= 3059 - 700 \times 0.371$$

$$= 2799.3 \text{ kJ/kg}$$

$$v_1 = 0$$

$$v_2 =$$

$$v_1 =$$

$$h_1 =$$

$$= 50$$

$$= 19$$

$$u_1 = h_1$$

$$= 19$$

$$D_1 =$$

table sch

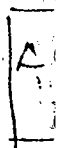
$$300 \text{ k}$$

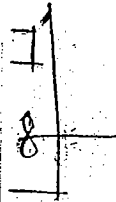
$$810 \text{ k}$$

$$\Delta P =$$

$$\Delta V$$

$$\Delta P$$





3
71

141
= 700 x 0.331

99.3 kg/kg

$$v_1 = \frac{0.6 \text{ m}^3}{\text{kg}} = x_1 v_{g1}$$

$$0.6 = x_1 \times 0.885$$

$$x_1 = \frac{0.6}{0.885} = 0.628$$

$$h_1 = h_{f1} + x_1 (h_{g1} - h_{f1})$$

$$= 504.7 + 0.628 (2706.3 - 504.7)$$

$$= 1997.3848 \text{ J/kg}$$

$$u_1 = h_1 - p_1 v_1$$

$$= 1997.38 - 200 \times 0.6$$

$$= 1887.38 \text{ J/kg}$$

$u_1 = v_1 = 0.6 \text{ m}^3/\text{kg}$ but condition is dry and saturated the table referring the v_g column for a value of $0.6 \text{ m}^3/\text{kg}$

800 kPa	0.6053	2724.7
810 kPa	0.5872	2726.1

$$\Delta p = -10 \text{ kPa} \quad \Delta v = 0.0181 \quad \Delta h = 1.4$$

$$\Delta v' = 0.0053 \quad \Delta h' = ?$$

$$\Delta p' = \frac{\Delta v'}{\Delta v} \times \Delta p = \frac{0.0053}{0.0181} \times (-10)$$

$$3150 - p_2 = -2.928$$

$$p_2 = 302.92 \text{ kPa}$$

$$\Delta h' = \frac{\Delta v'}{\Delta v} \times \Delta h$$

$$2742.7 - h_2 = \frac{0.0053}{0.0181} \times (-1.4)$$

$$h_2 = 2743.109$$

$$u_2 = h_2 - p_2 v_2$$

$$= 2725.1 - 302.92 \times 0.6 = 2543.348 \text{ J/kg}$$

$$v_{g1} = 0.885 \frac{\text{m}^3}{\text{kg}}$$

net cy process $W_2 = 0$

$$U_1 + Q = U_2 + 0$$

$$Q = U_2 - U_1$$

$$= 2543 - 1877$$

$$= 666 \text{ kJ/kg}$$

$$\text{total heat transfer: } 5 \times 666 = 3330$$

pg No 26 Qu. No 9

$$m_1 = 3 \text{ kg/min}$$

$$P_1 = 2 \text{ MPa}$$

$$T_1 = 300^\circ\text{C}$$

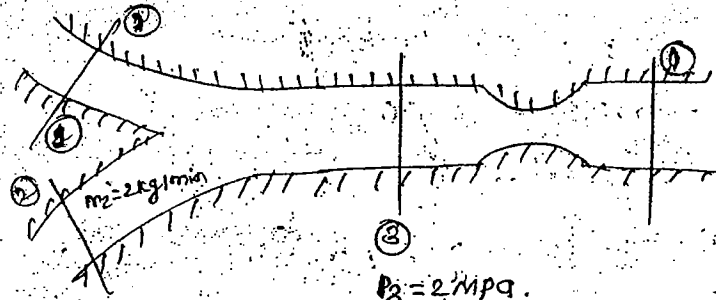
$$T_{\text{sat}} = 212^\circ\text{C}$$

$$T_1 > T_{\text{sat}}$$

Superheated state

$$h_1 = 3025 \text{ kJ/kg}$$

$$s_1 = 6.77 \text{ kJ/kg K}$$



$$P_2 = 2 \text{ MPa}$$

$$T_2 = 212^\circ\text{C}$$

$$T_{\text{sat}} = 212^\circ\text{C}$$

$T_2 > T_{\text{sat}}$ / Superheated state

$$h_2 = 2848.6 \text{ kJ/kg}$$

$$s_2 = 7.13 \text{ kJ/kg K}$$

$$P_3 = 2 \text{ MPa}$$

Mass balance

$$\text{Mass entering} = \text{Mass leaving}$$

$$m_1 + m_2 = m_3$$

$$m_3 = 2 + 3 = 5 \text{ kg/min}$$

Energy balance

$$\text{Energy entering} = \text{Energy leaving}$$

$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

$$3 \times 3025 + 2 \times 2848.6$$

$$= 5 h_3$$

$$h_3 = 3114.44 \text{ kJ/kg}$$

$$P_3 = 2 \text{ MPa}$$

$$\begin{array}{ccc} 300^\circ\text{C} & 3025 & 6.77 \\ \swarrow & \searrow & \swarrow \\ 212^\circ\text{C} & 2848.6 & 7.13 \end{array}$$

$$\begin{array}{ccc} 350^\circ\text{C} & 3138.6 & 7.96 \end{array}$$

$$\Delta T = -50^\circ\text{C} \quad \Delta h = -113.6$$

$$\Delta s = -0.19$$

$$\Delta h' = -89.4$$

$$\Delta T' = ? \quad \Delta h' = ? \quad \Delta s' = ?$$

$$\Delta T' = \frac{\Delta h'}{\Delta h} \times \Delta T$$

$$= \frac{-89.4}{-113.6} \times (-50)$$

$$= -39.34^\circ\text{C}$$

$$300 - T_3 = -39.35$$

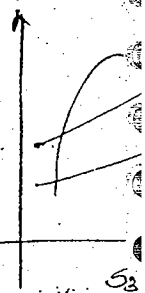
$$\boxed{339.35 = T_3}^\circ\text{C}$$

$$\Delta S' = \frac{C}{\Delta}$$

$$\Delta S_{\text{system}}$$

$$(\Delta S)_{\text{m}}$$

val



$$6.919 =$$

$$=$$

$$x =$$

$$h_2 =$$

$$\Delta S^I = \frac{\Delta h^I}{\Delta h} \Delta S = \frac{-894}{-113.6} \times (-0.19) = -0.15$$

$$6.77 - s_3 = -1.5$$

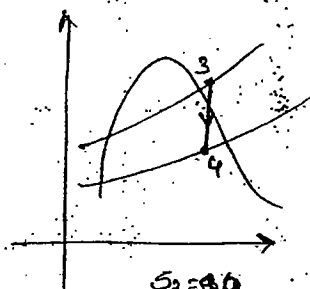
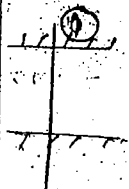
$$s_3 = 6.919 \text{ kJ/kg}$$

$$\begin{aligned} \Delta S_{\text{system}} &= \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2 \\ &= 5 \times 6.919 - 3 \times 6.72 - 2 \times 7.13 \\ &= -0.272 \text{ kJ/Kmin} \end{aligned}$$

$$(\Delta S)_{\text{surroundings}} = 0$$

$$(\Delta S)_{\text{min}} = (\Delta S)_{\text{surroundings}} + (\Delta S)_{\text{system}} = 0.0275 \text{ kJ/Kmin}$$

value is > 0 this is irreversible process



is leaving

kg/min

id

energy leaving

$$= \dot{m}_3 h_3$$

$$48.6$$

$$4 \text{ kJ/kg}$$

$$s_1 = 6.77$$

$$6 \text{ kJ/kg}$$

$$-113.6$$

$$\begin{aligned} 6.919 &= s_{f4} + x(s_{g4} - s_{f4}) \\ &= 0.106 + x(8.977 - 0.106) \end{aligned}$$

$$x = \frac{6.919 - 0.106}{8.977 - 0.106}$$

$$h_{f4} = x = 0.768$$

$$\begin{aligned} h_6 &= h_{f4} + x(h_{g4} - h_{f4}) \\ &= 129.3 + 0.268(2814.4 - 129.3) \\ &= 1937.86 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} v_6 &= x v_{g4} \\ &= 0.268 \times 129.4 \\ &= 34.6 \text{ m}^3/\text{kg} \end{aligned}$$

$$V = 44.72 \sqrt{\Delta h}$$

$$= 44.72 \sqrt{h_3 - h_4}$$

$$= 44.72 \sqrt{(3114.41 - 1937.86)}$$

$$= 1533.9 \text{ m/sec}$$

$$\dot{m} = \frac{A V}{v}$$

$$\frac{5}{60} = \frac{A \times 1533.9}{0.9938}$$

$$A = 5.395 \times 10^{-3} \text{ m}^2$$

$$A = \frac{\pi}{4} d^2$$

$$d = \sqrt{\frac{5.395 \times 10^{-3} \times 4}{\pi}} = 0.02620$$

Q410

$$p_1 = 15 \text{ bar}$$

$$T_1 = 200^\circ\text{C}$$

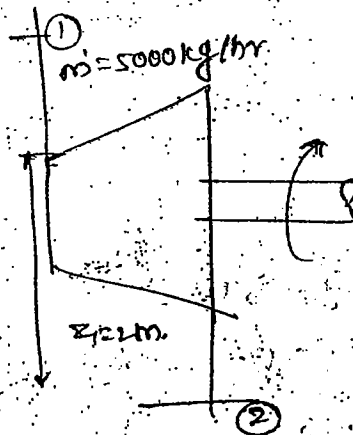
$$T_{\text{sat}} = 188^\circ\text{C}$$

$$T_1 > T_{\text{sat}}$$

Superheated steam

$$h_1 = 3038.9 \text{ kJ/kg}$$

$$s_1 = 6.921 \text{ kJ/kg}$$



$$\text{Velocity initial } v_1 = 80 \text{ m/s}$$

$$h_2 = h_{f2} + x_2(h_{g2} - h_{f2})$$

$$= 191.8 + 0.96(2582.9 - 191.8)$$

$$= 2489.17 \text{ kJ/kg}$$

$$v_2 = x_2 v_{g2}$$

$$= 0.96 \times 14.67$$

$$= 14.08 \text{ m}^3/\text{kg}$$

$$v_2 = 60 \text{ m/s}$$

Q411

Apply SFEE

$$\dot{m} \left(h_1 + \frac{v_1^2}{2000} + \frac{z_1 g}{1000} \right) + \frac{dQ}{dt}$$

$$= \dot{m} \left(h_2 + \frac{v_2^2}{2000} + \frac{z_2 g}{1000} \right) + \frac{dW}{dt}$$

$$\frac{dW}{dt} = \dot{m} (h_1 - h_2) + \dot{m} \left(\frac{v_1^2 - v_2^2}{2000} \right) + \frac{\dot{m} (z_1 - z_2) g}{1000}$$

$$= \frac{5000}{3600} (2038.9 - 2489.17) + \frac{5000}{3600} \left(\frac{80^2 - 40^2}{2000} \right)$$

$$+ \frac{5000}{3600} \frac{(2) \cdot 9.81}{1000}$$

$$= 763.513 + 3.33 + 0.02925$$

$$= 748 \text{ kW}$$

$$\left(\frac{dW}{dt} \right)_{KE=PEO} = 763.51 \text{ kW}$$

$$\left(\frac{dW}{dt} \right)_{\text{with KE+PE}} = 766.81 \text{ kW}$$

$$\dot{m} = \frac{AV}{V}$$

$$\frac{5000}{3600} = \frac{A \times 80}{0.1697}$$

$$= \frac{A \times 40}{14.08}$$

$$A_1 = 2.9486 \text{ m}^2$$

$$A_2 = 0.488 \text{ m}^2$$

$$\frac{\pi}{4} d_1^2 = 2.9486$$

$$\frac{\pi}{4} d_2^2 = 0.488$$

$$d_1 = 1.9375$$

$$d_2 = 0.788$$

Unit

bar

9.6

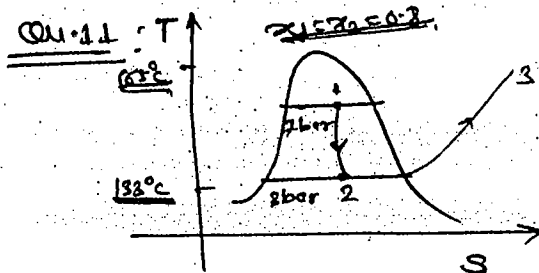
$$x_2 (h_{g2} - h_{f2})$$

$$0.96 (2582.9 - 191.2)$$

$$17 \text{ J/kg}$$

7

1 kg



$$h_1 = h_{f1} + x_1 (h_{g1} - h_{f1})$$

$$h_1 = 6473 + 0.8(2702 - 6473)$$

$$= 2349.06 \text{ kJ/kg}$$

$$s_1 = s_{f1} + x_1(s_{g1} - s_{f1})$$

$$= 1.992 + 0.8(6.705 - 1.992)$$

$$= \underline{\underline{5.762 \text{ kJ/kgK}}}$$

State 2: $h_2 = h_{f2} + x_2(h_{g2} - h_{f2})$

$$= 651.4 + 0.8(2724.7 - 651.4)$$

$$= 2310.04 \text{ kJ/kg}$$

$$s_2 = s_{f2} + x_2(s_{g2} - s_{f2})$$

$$= 1.672 + 0.8(6.991 - 1.672)$$

$$= 5.927 \text{ kJ/kgK}$$

State 3: $T_3 - T_{\text{sat}} = 66.5^\circ\text{C}$

$$T_3 - 133.5 = 66.5$$

$$T_3 = \underline{\underline{200^\circ\text{C}}}$$

$$h_3 = 2865.5 \text{ kJ/kg}$$

$$s_3 = 7.312 \text{ kJ/kgK}$$

1-2

$$\Delta h = h_2 - h_1$$

$$= 2310.04 - 2349.06$$

$$= -39.02 \text{ kJ/kg}$$

$$\Delta s = s_2 - s_1$$

$$= 5.927 - 5.762$$

$$= \underline{\underline{0.165 \text{ kJ/kgK}}}$$

2-3

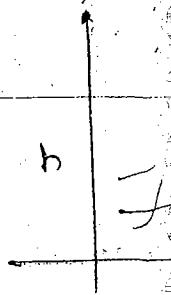
$$\Delta h = h_3 - h_2$$

$$= 2865.5 - 2310.04$$

$$= 555.46$$

$$u = 3 =$$

$$27.312$$



Q1.3 V

State 1

$$h_1 =$$

$$=$$

$$=$$

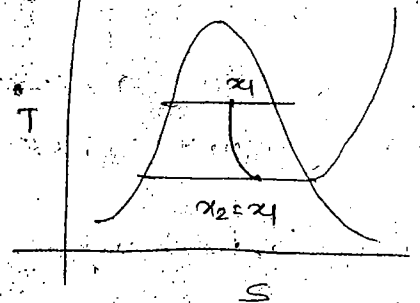
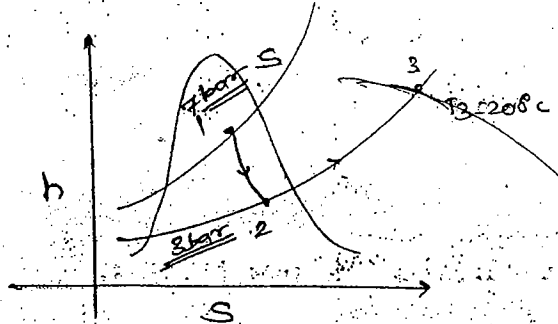
$$u_1 =$$

State 2

$$u_2 =$$

$$\Delta S = S_3 - S_2$$

$$= 9.312 - 8.927 = 1.38$$



Q.3 $V = 1 \text{ m}^3$

State 1 $v_1 = v_{f1} + x_1 (v_{g1} - v_{f1})$
 $= v_{f1} + x_1 (v_{fg2} - v_{f1})$
 $= 0.001073 + 0.7 (0.6058 - 0.001073)$

$$= 0.424 \frac{\text{m}^3}{\text{kg}}$$

$$h_1 = h_{f1} + x_1 (h_{fg1})$$

$$= 561.47 + 0.7 (2163.8)$$

$$= 2076 \text{ kJ/kg}$$

$$U_1 = h_1 - P_1 v_1 = 2076 - 300 \times 0.424 = 1948.8 \text{ kJ/kg}$$

State 2 $v_1 = v_2$

$$0.424 = v_{f2} + x_2 (v_{g2} - v_{f2})$$

$$= 0.001661 + x_2 (0.8857 - 0.001661)$$

$$x_2 = 0.47$$

$$h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

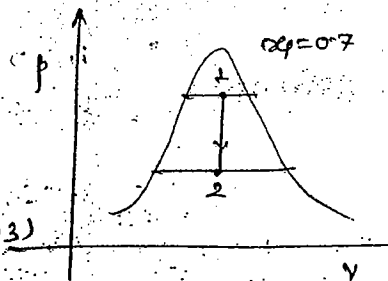
$$= 564.7 + 0.47 (2201.9)$$

$$= 1539.5 \text{ kJ/kg}$$

$$U_2 = h_2 - P_2 v_2$$

$$= 1539.5 - 200 \times 0.424$$

$$= 1454.87 \text{ kJ/kg}$$



$$m^{\circ} = \frac{V_1}{v_1} = \frac{1}{0.429} = 2.358 \text{ kg}$$

$$\text{mass of vapor} = 0.7 \times 2.35 = 1.645$$

$$\text{mass of liquid} = 0.3 \times 2.35 = \underline{0.705}$$

Energy loss = change

It is a non flow process volume is constant work done is zero. heat transferred

$$\begin{aligned} Q &= m(u_2 - u_1) \\ &= 2.35 (1454.87 - 1948.8) \\ &= \underline{-1160.9355 \text{ kJ}} \end{aligned}$$

heat loss to surrounding

Pg. No 52 Q. No 17 & 18

<u>Am 17</u>	u_f	h_f	s_f	s_g	u_g	h_g
	85.76	89.05	0.3657	5.6153	1244.5	1418.0

Am (d)

$$s_g - s_f = \frac{h_g - h_f}{T_{\text{sat}}}$$

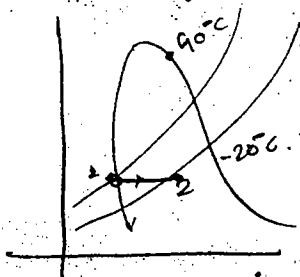
$$\begin{aligned} h_f &> u_f \\ h_g &> u_g \end{aligned}$$

$$253 [5.6153 - 0.3657] = \underline{1418 - 89.05}$$

Single digit values are entropy

double & triple digit are u_f & h_f

four digit value are h_g & u_g



$$h_1 = h_2$$

@ 40°C

$$h_1 = h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

$$371.43 = 89.05 + x_2 (1418 - 89.05)$$

$$\boxed{x_2 = 0.212}$$

(17)

v_f at
(u_f)

(h_f)

isobar

pg No 23 Q. No 17 & 18

Q. 2

Q. 3

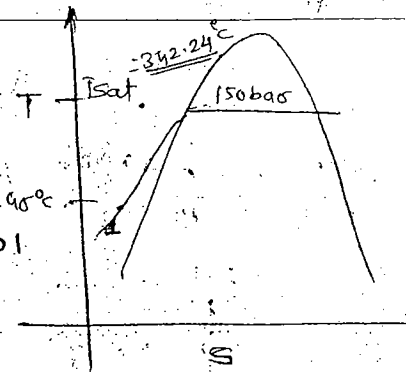
Q. 4

Q. 5

19.

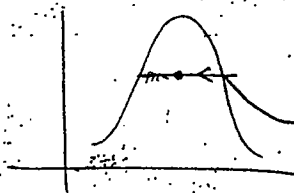
$$v_f \text{ at } 45^\circ\text{C} = 0.001010 \text{ m}^3/\text{kg}$$

$$\begin{aligned} (u_f)_{45^\circ\text{C}} &= (h_f)_{45^\circ\text{C}} - P_f v_f \\ &= 188.45 - 150 \times 100 \times 0.00101 \\ &= 188.44 \text{ kJ/kg} \end{aligned}$$



$$\begin{aligned} (h_f)_{45^\circ\text{C}} &= 188.45 \text{ kJ/kg} \\ (h_f)_{45^\circ\text{C}} &= (u_f)_{45^\circ\text{C}} + P(v_f)_{45^\circ\text{C}} \\ &= 188.44 + 150 \times 100 \times 0.00101 \\ &= 203.60 \text{ kJ/kg} \end{aligned}$$

pg NO 23 Q4 NO 1



Q4.2

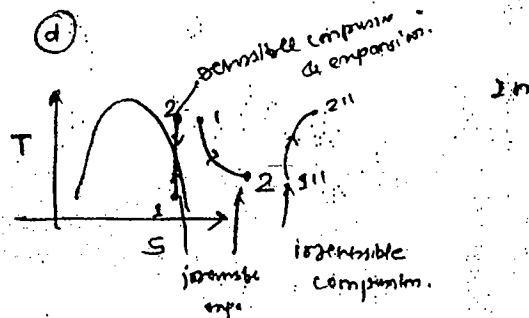
$$\begin{aligned} \uparrow P_{\text{sat}} &\rightarrow \uparrow T_{\text{sat}} \\ &\rightarrow \downarrow h_{fg} \end{aligned}$$

$$\begin{aligned} P_{\text{sat}} \downarrow &\rightarrow \text{specific volume} \uparrow \\ x \uparrow &\rightarrow s \uparrow \end{aligned}$$

Q4.3

(d)

Q4.4:



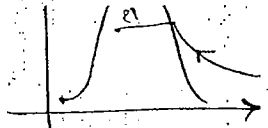
Q4.5:

$$\begin{aligned} v_g - v_f &= \frac{ds}{dp} \times \frac{h_{fg}}{T_{\text{sat}}} \\ &= \frac{K}{\text{kPa}} \times \frac{\text{kJ/kg}}{K} \\ \frac{\text{kJ}}{\text{kg} \cdot \text{kg}} &= \frac{\text{m}^3}{\text{kg}} \end{aligned}$$

Q4.6

- R - solid region
- s - solid + liquid
- l - liquid region
- lv - liquid + vapor
- v - superheated vapor
- x - superheated gas
- v - solid + vapor

05)



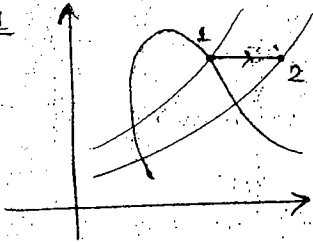
Q. 8

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{0.286} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

$$\frac{n-1}{n} = 0.286$$

$$n = 1.4$$

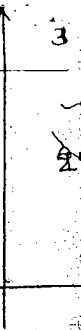
Q. 9



h constant in the whole

$P \downarrow \rightarrow T \uparrow \rightarrow S \uparrow$

STIRLING



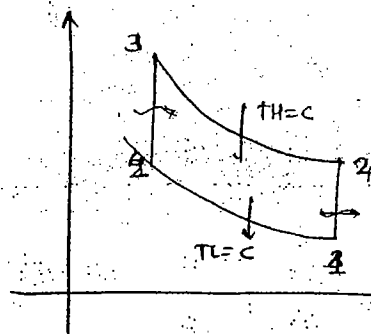
A Stirling
Regenerative
heat to

$$\frac{1-2}{1-2} = \frac{T_1}{T_2}$$

2-3

AIR CYCLE

STIRLING CYCLE

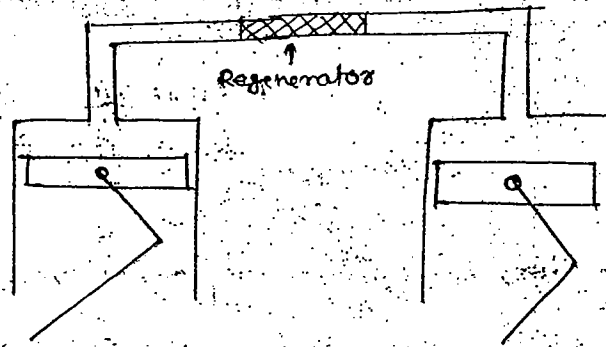


1-2 $\Rightarrow$ Reversible isothermal heat rejection

2-3 $\Rightarrow$ constant volume heat supply (internal)

3-4 $\Rightarrow$ Reversible isothermal heat supply

4-1 $\Rightarrow$ constant vol^m heat rejection (internal)



A Stirling cycle function in combination with a regenerator. Regenerator is a device which alternately stores & rejects heat to run the engine.

1-2 $T=C$

$$\begin{aligned} 1Q_2 = 1W_2 &= p_1 v_1 \ln \left(\frac{v_2}{v_1} \right) \\ &= RT_L \ln \left(\frac{v_2}{v_1} \right) \\ &= RT_L \ln \left(\frac{v_1}{v_2} \right) \end{aligned}$$

2-3 $V=C$

$$\frac{p_2}{T_2} = \frac{p_3}{T_3}$$

$$2Q_3 = cv(T_3 - T_2)$$

3-4 $\gamma = \gamma$

$$3Q_4 = 3Q_4 = P_3 V_3 \ln \frac{V_4}{V_3}$$

$$= R T_H \ln \frac{V_4}{V_3}$$

4-1 $\gamma = \gamma$

$$\frac{P_4}{T_4} = \frac{P_1}{T_1}$$

$$4Q_1 = C_V (T_4 - T_1)$$

$$\eta_{\text{thermal}} = \frac{Q_S - Q_R}{Q_S} = \frac{R T_H \ln \frac{V_4}{V_3} - R T_L \ln \frac{V_2}{V_1}}{R T_H \ln \frac{V_4}{V_3}}$$

$$\boxed{\eta_{\text{th}} = \frac{T_H - T_L}{T_H}}$$

η_{thermal} of Stirling cycle is same as η_{Carnot} cycle.

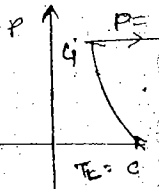
A regenerator is a device which automatically stores and rejects heat hence it is never having 100% efficiency.

$\therefore$ The actual efficiency of Stirling cycle is less than the Carnot cycle.

In Stirling back work, pump work or compressive work is less when ω is high and stroke volume is less when compared to Carnot cycle, and M.E.P is high when compared to Carnot cycle.

Stirling cycle ran at 2700 rpm with 0.3% thermal efficiency.

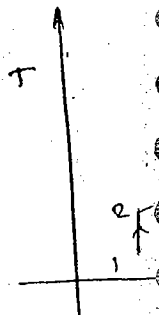
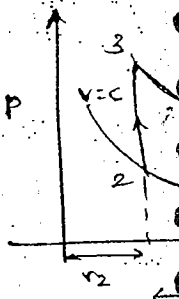
Pressure



Efficiency

here bar and m.e

Ottoc

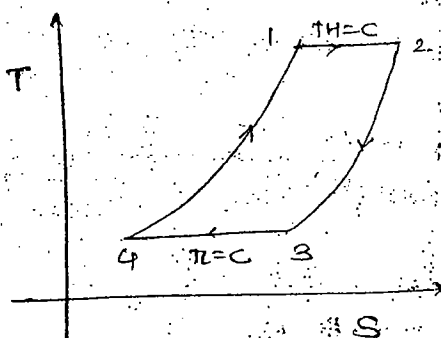
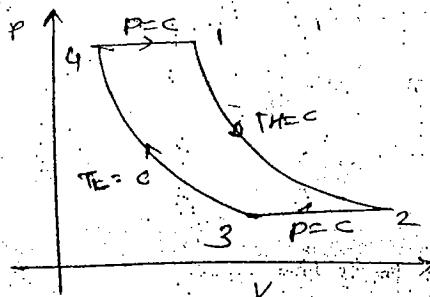


$$2 T_L \ln \frac{V_2}{V_1}$$

$$\frac{4}{13}$$

it cycle.
stored and
energy
less than the
piston or
id stroke
cycle, and
ile.
with 0.3%

ERICSON CYCLE

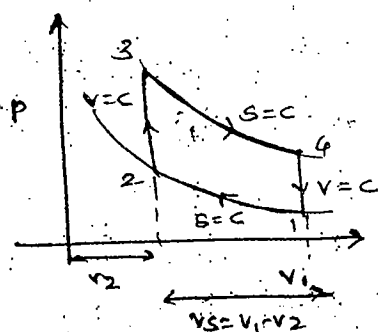


- 1-2 = Reversible isothermal expansion
- 2-3 = Constant pressure heat rejection isothermal
- 3-4 = Reversible isothermal comp
- 4-1 = constant pressure heat sup isothermal

$$\eta = \frac{T_H - T_L}{T_H}$$

Ericson cycle is an example of land gas turbine cycle here back work is less. Net is high stroke vol is le and m.e.p is high. when compared to carnot cycle

OTTO cycle / SI cycle

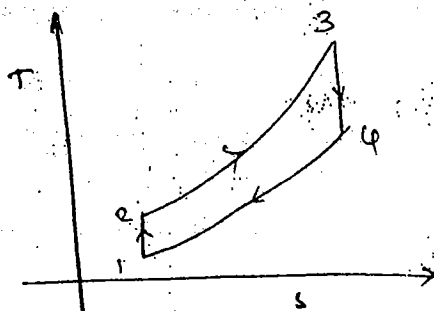


- 1-2 = Reversible adiabatic compression
- 2-3 = constant volm heat supplied
- 3-4 = reversible adiabatic expansion
- 4-1 = constant volm heat rejection

compression ratio

$$\gamma_R = \frac{V_1}{V_2} = \frac{V_S + V_C}{V_C}$$

$$\frac{V_S}{V_C} = (\gamma_R - 1)$$



1-2 - Reversible adiabatic compression

2-3 constant volume heat supply

3-4 Reversible adiabatic expansion

4-1 constant volume heat rejection

1-2 Reversible adiabatic compression

$$Q=0 \quad S=C$$

$$P_1 V_1^r = P_2 V_2^r$$

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^r = P_1 (r_k)^r \quad \text{--- (1)}$$

$$T_1 V_1^{r-1} = T_2 V_2^{r-1}$$

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{r-1} = T_1 (r_k)^{r-1} \quad \text{--- (2)}$$

$$T_1 P_1^{\frac{1-r}{r}} = T_2 P_2^{\frac{1-r}{r}}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{r-1}{r}} \quad \text{--- (3)}$$

$$W_2 = \frac{P_1 V_1 - P_2 V_2}{r-1}$$

$$= \frac{R(T_1 - T_2)}{r-1} = C_V (T_1 - T_2) \quad \text{--- (4)}$$

2-3 V=C

$$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$T_3 = T_2 \left(\frac{P_3}{P_2} \right) \quad \text{--- (5)}$$

$$2Q_3 = C_V (T_3 - T_2) \quad \text{--- (6)}$$

54

P_3

P_2

T_3

T_3

31

4-1

$\frac{P}{T}$

T_4

40

Therm

3-4 Reversible adiabatic expansion

$$Q=0, \quad S=C$$

$$P_3 V_3^\gamma = P_4 V_4^\gamma$$

$$P_3 = P_4 \left(\frac{V_4}{V_3} \right)^\gamma \\ = P_4 (r_E)^\gamma \quad \text{--- (7)}$$

$$P_3 V_3^{\gamma-1} = P_4 V_4^{\gamma-1}$$

$$P_3 = P_4 \left(\frac{V_4}{V_3} \right)^{\gamma-1}$$

$$P_3 = P_4 (r_E)^{\gamma-1} \quad \text{--- (8)}$$

$$T_3 P_3^{\frac{1-\gamma}{\gamma}} = T_4 P_4^{\frac{1-\gamma}{\gamma}}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (9)}$$

$$W_{34} = \frac{P_3 V_3 - P_4 V_4}{\gamma - 1}$$

$$= \frac{R(T_3 - T_4)}{\gamma - 1}$$

$$= C_V(T_3 - T_4) \quad \text{--- (10)}$$

4-1 V=C

$$\frac{P_4}{T_4} = \frac{P_1}{T_1}$$

$$T_4 = \frac{P_4}{P_1} \times T_1 \quad \text{--- (11)}$$

$$Q_1 = C_V(T_4 - T_1) \quad \text{--- (12)}$$

$$\eta_{\text{thermal}} = \frac{Q_S - Q_R}{Q_S}$$

$$= 1 - \frac{Q_R}{Q_S}$$

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

$$= f(r_E, \gamma)$$

②

④

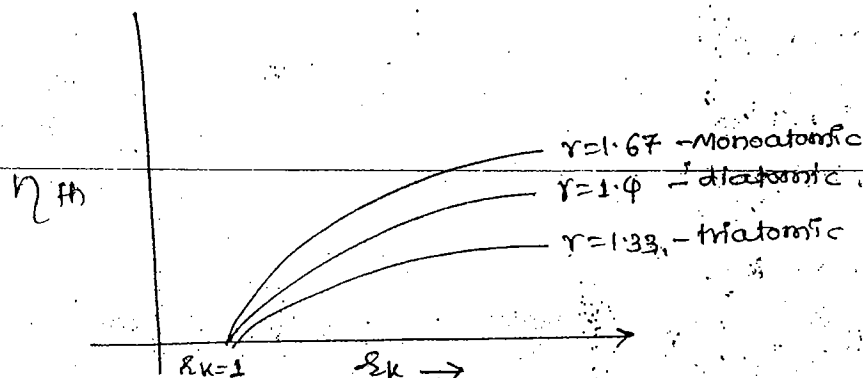
$$r_E = 2K$$

$$\frac{V_1}{V_2} =$$

$$\eta_k =$$

$$1-2$$

$$Q =$$

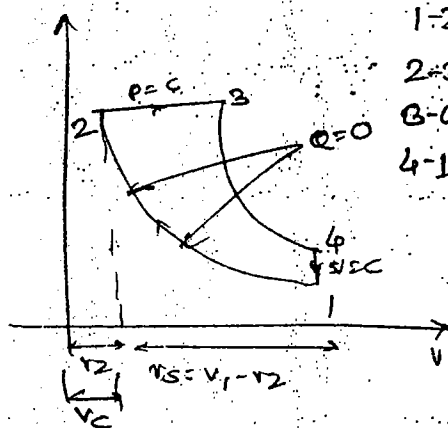


$$\epsilon_k = \text{constant} \quad \begin{matrix} \gamma \uparrow & \eta_{th} \uparrow \\ \gamma \downarrow & \eta_{th} \downarrow \end{matrix}$$

$$\gamma = \text{constant} \quad \begin{matrix} \epsilon_k \uparrow & \eta_{th} \uparrow \\ \epsilon_k \downarrow & \eta_{th} \downarrow \end{matrix}$$

The maximum compression ratio up to which we can operate a SI engine/otto cycle is limited to 10 this is because of the detonating characteristic of fuel under consideration

Diesel cycle



1-2 $\Rightarrow$ reversible adiabatic compression

2-3 $\Rightarrow$ constant pressure heat supply

3-4 $\Rightarrow$ reversible adiabatic expansion

4-1 $\Rightarrow$ constant volume heat rejection

$$\text{Comp ratio} = r_k = \frac{v_1}{v_2}$$

$$\text{cut off ratio } r_c = \frac{v_3}{v_2}$$

$$\text{Expansion ratio} = r_e = \frac{v_4}{v_3} = \frac{v_1}{v_3}$$

$$2-3$$

$$3-4$$

$$\frac{V_1}{V_2} = \frac{V_1}{V_3} \times \frac{V_3}{V_2}$$

$$\boxed{\epsilon_k = \epsilon_E \times \epsilon_C}$$

1-2 $Q=0$ $S=\text{constant}$ } Reversible adiabatic process

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^\gamma = P_1 \epsilon_k^\gamma \quad \text{--- (1)}$$

$$P_1 V_1^{\gamma-1} = P_2 V_2^{\gamma-1}$$

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1} = T_1 \epsilon_k^{\gamma-1} \quad \text{--- (2)}$$

$$T_1 P_1^{\frac{1-\gamma}{\gamma}} = T_2 P_2^{\frac{1-\gamma}{\gamma}}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (3)}$$

$$W_2 = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$W_2 = \frac{R C (T_1 - T_2)}{\gamma - 1} = C V (T_1 - T_2) \quad \text{--- (4)}$$

2-3 constant pressure process

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$T_3 = \frac{V_3}{V_2} \times T_2 \quad \text{--- (5)}$$

$$Q_{23} = C_P (T_3 - T_2) \quad \text{--- (6)}$$

3-4 $Q=0$ $S=\text{constant}$ (reversible Adiabatic)

$$P_3 V_3^\gamma = P_4 V_4^\gamma$$

$$P_3 = P_4 \left(\frac{V_4}{V_3} \right)^\gamma$$

$$= P_4 (\epsilon_E)^\gamma \quad \text{--- (7)}$$

$$\boxed{\epsilon_E < \epsilon_k}$$

we can
to 10
b/c of fuel

compression
not supply
& expansion
at rejection

$$\frac{V_1}{V_2}$$

$$\frac{V_3}{V_2}$$

$$= \frac{V_4}{V_3} = \frac{V_1}{V_3}$$

$$B V_3 = 1414$$

$$T_3 = T_4 \left(\frac{V_4}{V_3} \right)^{\gamma-1}$$

$$= T_4 (\xi_E)^{\gamma-1} \quad \text{--- (8)}$$

$$T_3 P_3^{\frac{1-\gamma}{\gamma}} = T_4 P_4^{\frac{1-\gamma}{\gamma}}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (9)}$$

$$3W_4 = \frac{P_3 V_3 - P_4 V_4}{\gamma-1} = \frac{P(T_3 - T_4)}{\gamma-1} = C_V (T_3 - T_4) \quad \text{--- (10)}$$

$$\underline{4-1} \quad \underline{V=C}$$

$$\frac{P_4}{T_4} = \frac{P_1}{T_1}$$

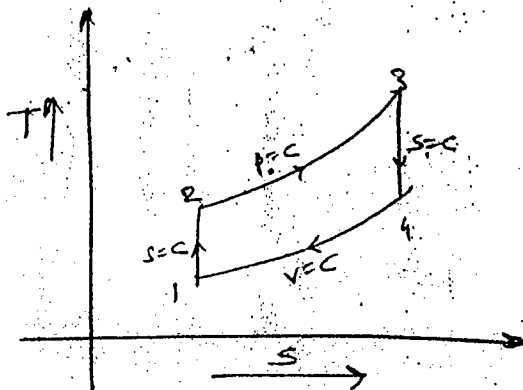
$$T_4 = T_1 \left(\frac{P_4}{P_1} \right) \quad \text{--- (11)}$$

$$4Q_1 = C_V (T_4 - T_1) \quad \text{--- (12)}$$

$$\eta_{\text{thermal}} = \frac{1 - Q_R}{Q_S}$$

$$= 1 - \frac{C_V (T_4 - T_1)}{C_P (T_3 - T_2)}$$

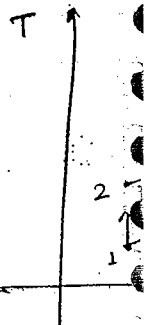
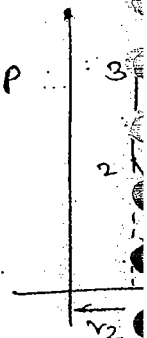
$$= 1 - \frac{1}{\gamma \xi_K^{\gamma-1}} \left[\frac{\xi_E^{\gamma-1} - 1}{(\xi_E - 1)} \right] = f(\xi_K, \xi_E, \gamma)$$

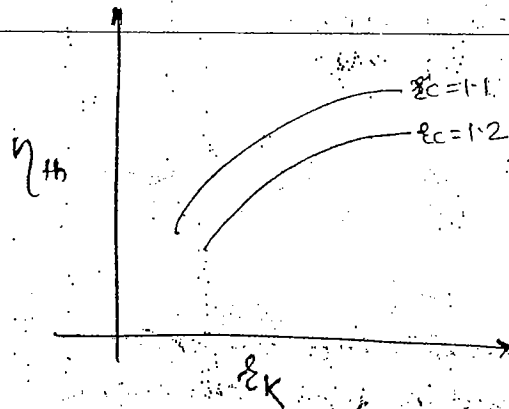


η_{th}

The op
between
becaus
greater

Dual





$$\left. \begin{array}{l} r_k \text{ const} \\ r_c \text{ const} \end{array} \right\} \begin{array}{l} r_c \uparrow \eta_{th} \downarrow \\ r_c \downarrow \eta_{th} \uparrow \end{array}$$

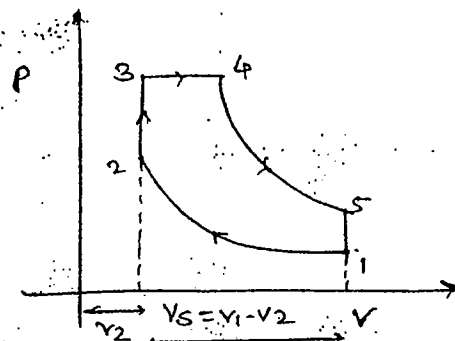
$$\left. \begin{array}{l} r_c \text{ const} \\ r_k \text{ const} \end{array} \right\} \begin{array}{l} r_k \uparrow \eta_{th} \uparrow \\ r_k \downarrow \eta_{th} \downarrow \end{array}$$

$$\left. \begin{array}{l} r_k, r_c \text{ const} \end{array} \right\} \begin{array}{l} r \uparrow \eta_{th} \uparrow \\ r \downarrow \eta_{th} \downarrow \end{array}$$

(T₄) — (10)

The operating range of r_k for diesel cycle are between 12 to 21 the optimum being around 16 to 20 because r_k is used high the η_{th} of diesel cycle is greater than η_{th} of otto cycle.

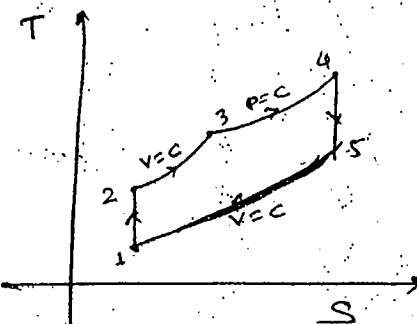
Dual CYCLE / SABATHE CYCLE



$$\text{compression ratio} = r_k = \frac{V_1}{V_2}$$

$$\text{cut off ratio} = r_c = \frac{V_4}{V_3} = \frac{V_4}{V_2}$$

$$\text{Expansion ratio} = r_e = \frac{V_5}{V_4} = \frac{V_1}{V_2}$$



r_k, r_c, r

$$Q_S = C_V (T_3 - T_2) + C_P (T_4 - T_3)$$

$$Q_R = C_V (T_5 - T_1)$$

$$r_p = \text{pressure ratio} = \text{expansion ratio}$$

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

$$\eta_{\text{thermal}} = 1 - \frac{Q_R}{Q_S}$$

$$= 1 - \frac{C_V (T_5 - T_1)}{C_V (T_3 - T_2) + C_P (T_4 - T_3)}$$

$$\eta_{\text{thermal}} = 1 - \frac{1}{r_k^{r-1}} \left\{ \frac{r_p r_c^{r-1}}{(r_p - 1) + r_p (r_c - 1)} \right\}$$

$$= f(r_k, r_p, r_c, r)$$

$\gamma = 1$ dual cycle converted to otto cycle

$$(\eta)_{\text{dual}} = (\eta)_{\text{diesel}}$$

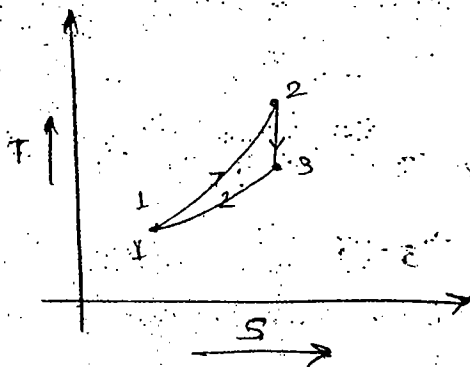
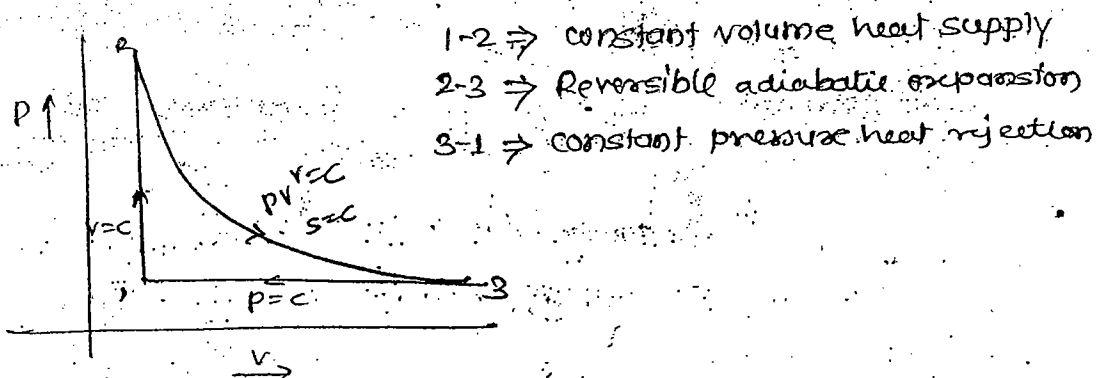
$\gamma = 1$

$$(\eta)_{\text{dual}} = (\eta)_{\text{otto}}$$

Modified Rankine cycle is another cycle which is having 5 processes and is used in for steam engine

Lenoir cycle

- It is used in pulse jet engine



1-2 $v=c$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \frac{P_2}{P_1} \times T_1 \quad \text{--- (1)}$$

$$Q_2 = C_v(T_2 - T_1) \quad \text{--- (2)}$$

2-3

Rev

B

2K

3-1

pressure

η_{thermal}

no back
for The

which is
in engine

at supply
expansion
at rejection

2-3 Reversible adiabatic expansion

$$P_2 V_2^\gamma = P_3 V_3^\gamma$$

$$T_2 V_2^{\gamma-1} = T_3 V_3^{\gamma-1}$$

$$T_2 P_2^{\frac{\gamma}{\gamma-1}} = T_3 P_3^{\frac{\gamma}{\gamma-1}}$$

$$2K_3 = \frac{P_2 V_2 - P_3 V_3}{\gamma - 1} = \frac{R(T_2 - T_3)}{\gamma - 1}$$

3-1 P=C

$$P \frac{V_3}{T_3} = \frac{V_1}{T_1}$$

$$3Q_1 = C_p(T_3 - T_1)$$

$$\text{pressure ratio} = \text{Expansion ratio} = \frac{P_2}{P_1} = \epsilon_p$$

$$\eta_{\text{thermal}} = 1 - \frac{Q_R}{Q_S}$$

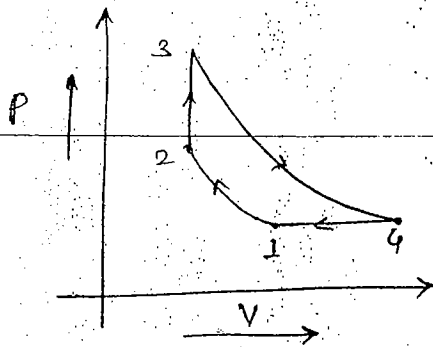
$$= 1 - \frac{C_p(T_3 - T_1)}{C_v(T_2 - T_1)}$$

$$= 1 - \frac{\gamma [\epsilon_p^{1/\gamma} - 1]}{[\epsilon_p - 1]}$$

$$= f(\gamma, \epsilon_p)$$

no back work is here no compression work which is high
The moving part are less. The work ratio is unity

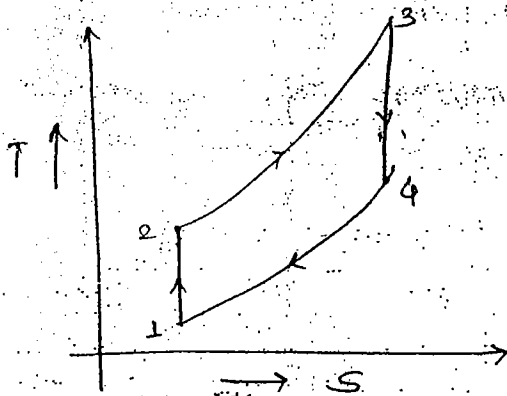
ATKINSON CYCLE



- 1-2 $\Rightarrow$ reversible adiabatic compression
- 2-3 $\Rightarrow$ constant volume heat supplied
- 3-4 $\Rightarrow$ Reversible adiabatic expansion
- 4-1 $\Rightarrow$ constant pressure heat rejection

Compression ratio $\epsilon_K = \frac{V_1}{V_2}$

Expansion ratio $\epsilon_E = \frac{V_4}{V_3}$



$\epsilon_E > \epsilon_K$ in atkinson cycle.

heat supplied $Q_S = c_v (T_3 - T_2)$

heat rejected $Q_R = c_p (T_4 - T_1)$

$\eta_{\text{thermal}} = 1 - \frac{Q_R}{Q_S}$

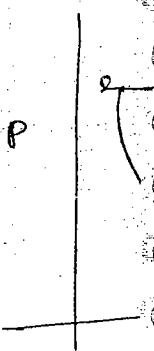
$\eta = 1 - \frac{c_p (T_4 - T_1)}{c_v (T_3 - T_2)}$

$= 1 - \frac{\gamma [\epsilon_E - \epsilon_K]}{[\epsilon_E^\gamma - \epsilon_K^\gamma]}$

Technical

were out
successful
for conv
at toggle
toggle to

Bryton



- 1-2 $\Rightarrow$ Revers
- 2-3 $\Rightarrow$ const
- 3-4 $\Rightarrow$ Revers
- 4-1 $\Rightarrow$ const

Comp

Expan

preheat

Heat supply

Heat reject

η_{therm}

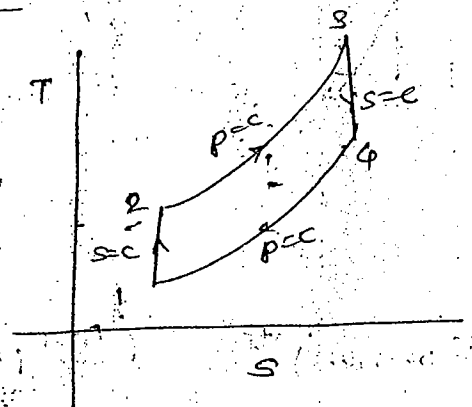
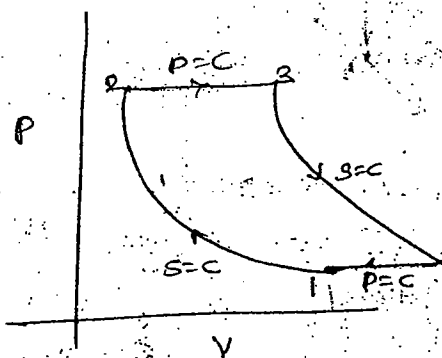
compression
heat supplied
expansion
heat rejection

son cycle:

Technically speaking

Atkinson cycle is higher η and higher work output when compared to Otto cycle. It is was successful it could have been present day. i.e. engine cycle for converting cv heat rejection to cp heat rejection. at toggle joint is used. excessive wear and tear of the toggle joint resulted in the failure of the cycle.

Brayton cycle or Joule cycle



- 1-2 $\Rightarrow$ Reversible adiabatic compression
- 2-3 $\Rightarrow$ constant pressure heat supplied
- 3-4 $\Rightarrow$ Reversible adiabatic expansion
- 4-1 $\Rightarrow$ Constant pressure heat rejection

$$\text{Compression ratio} = r_k = \frac{V_1}{V_2}$$

$$\text{Expansion ratio} = r_E = \frac{V_4}{V_3}$$

$$\text{pressure ratio} = r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

$$\text{Heat supplied } Q_S = c_p (T_3 - T_2)$$

$$\text{Heat rejected } Q_R = c_p (T_4 - T_2)$$

$$\eta_{\text{thermal}} = 1 - \frac{Q_R}{Q_S}$$

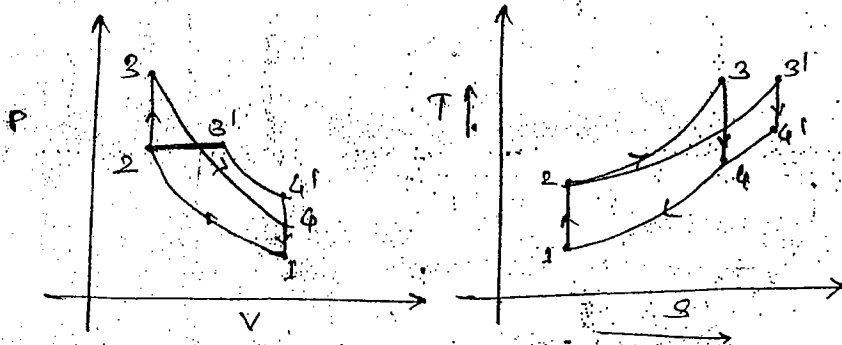
$$= 1 - \frac{c_p (T_4 - T_1)}{c_p (T_3 - T_2)}$$

$$= 1 - \left(\frac{1}{r_p} \right)^{\frac{\gamma-1}{\gamma}} = 1 - \left(\frac{1}{r_k} \right)^{\gamma-1} = f(r_k, \gamma)$$

Comparison cycle

Whenever we compare we compare only 3 cycles
i.e. otto, diesel and dual. For any comparison dual
cycle is always in between otto & diesel

① Compression ratio and heat supplied, constant.



(Peak pressure) otto > (Peak pressure) diesel

(Expansion ratio) otto > (Expansion ratio) diesel

(Peak temp) otto > (Peak temp) diesel

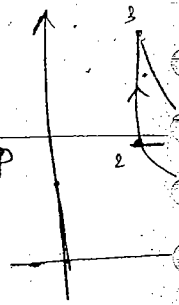
(Heat rejected) otto < (Heat rejected) diesel

(Temp at beginning of heat rejection) otto < (Temp at beginning of heat rejection) diesel

(Work in cycle) otto > (Work in diesel)

(η_{thermal}) otto > (η_{thermal}) diesel

② comp



(Peak

(Peak temp

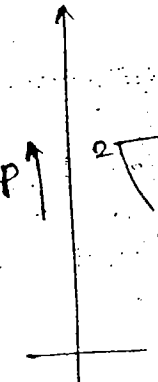
(Work)

(Heat s

(η_{therm}

(Expansion

③ Peak



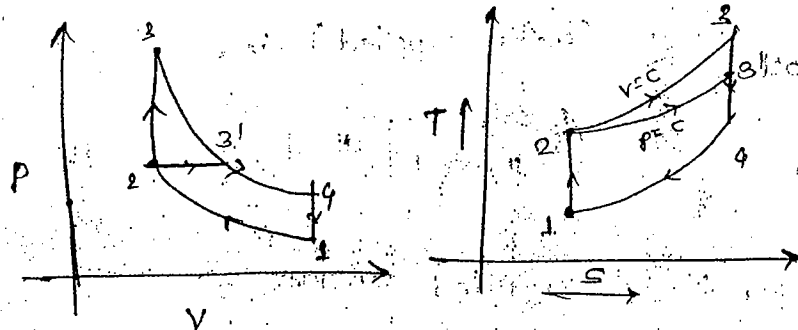
(cor.

(Temp
Cor

② compression ratio and heat rejection constant.

cycles
on dual

and



(Peak pressure) otto > (Peak pressure) diesel

(Peak temp) otto > (Peak temp) diesel

(Work) otto > (Work) diesel

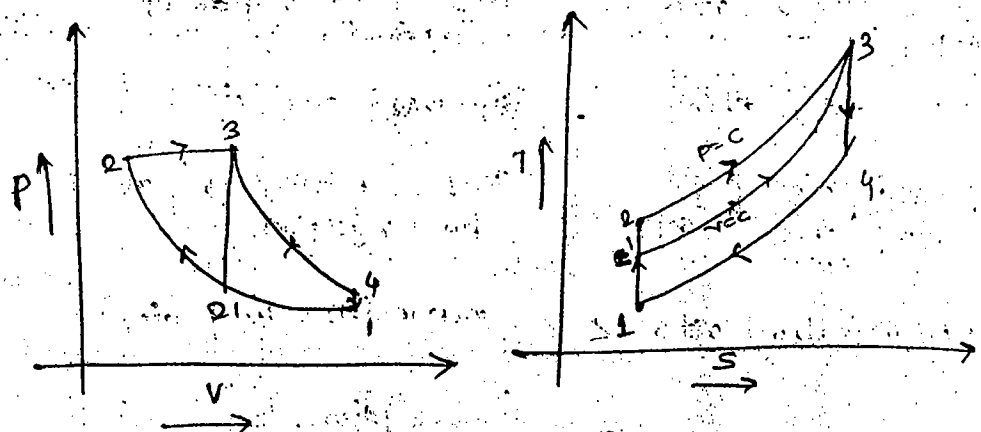
(Heat supplied) otto > (Heat supplied) diesel

(η_{thermal}) otto > (η_{thermal}) diesel

(Expansion ratio) otto > (Expansion ratio) diesel

③ Peak pressure, peak temp, heat rejected constant

and



(compression ratio) otto < (compression ratio) diesel.

(Temp at end of compression) otto < (Temp at end of compression) diesel

$$(Work)_{otto} < (Work)_{diesel}$$

$$(Heat\ supplied)_{otto} < (Heat\ supplied)_{diesel}$$

$$(\eta_{thermal})_{otto} < (\eta_{thermal})_{diesel}$$

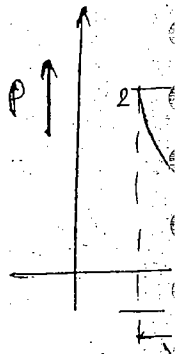
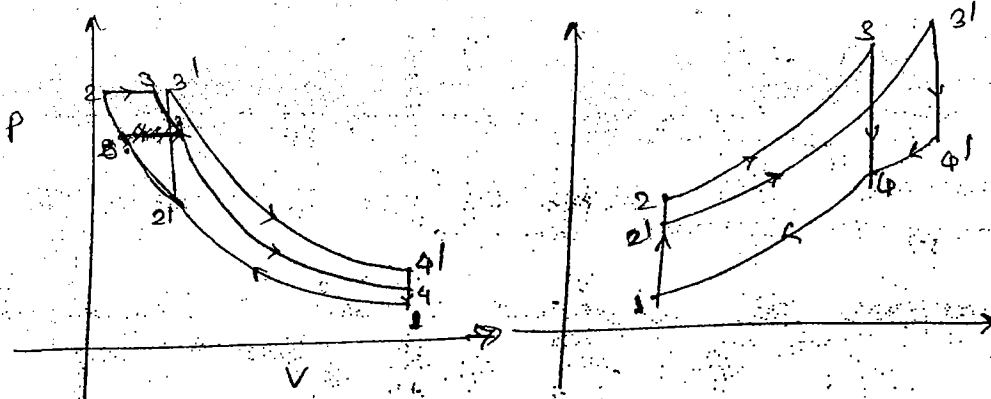
peak pr

figure 1
all. co

(heat

pg NO 20 pr

Peak pressure and heat supplied constant



$$(Compression\ ratio)_{otto} < (Compression\ ratio)_{diesel}$$

$$(Peak\ temp)_{otto} > (Peak\ temp)_{diesel}$$

$$(Temp\ at\ end\ of\ compression)_{otto} > (Temp\ at\ end\ of\ compression)_{diesel}$$

$$(Heat\ rejected)_{otto} > (Heat\ rejected)_{diesel}$$

$$(Temp\ @\ beginning\ of\ heat\ rejection)_{otto} > (Temp\ @\ beginning\ of\ heat\ rejection)_{diesel}$$

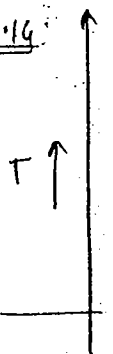
$$(Expansion\ ratio)_{otto} < (Expansion\ ratio)_{diesel}$$

$$(Work)_{otto} < (Work)_{diesel}$$

$$(\eta_{thermal})_{otto} < (\eta_{thermal})_{diesel}$$

$\eta_{thermal}$

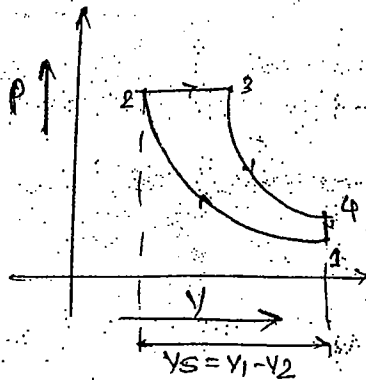
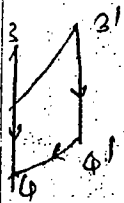
Qu. 14



peak pressure and workdone is constant.

figure is same as previous
all comparison is same as previous except
(heat supplied) otto > (heat supplied) diesel

pg No. 20 prb No. 13 :



$$r_k = \frac{v_1}{v_2} = 15$$

$$v_1 = 15 v_2$$

$$\text{cut off} = (v_3 - v_2)$$

$$v_3 - v_2 = \frac{6.5}{100} (v_1 - v_2)$$

$$= \frac{6.5}{100} (15 v_2 - v_2)$$

$$v_3 = 1.91 v_2$$

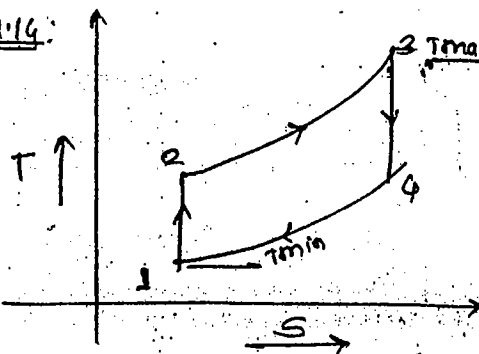
$$r_{\text{cut off}} = \frac{v_3}{v_2} = 1.91$$

$$\eta_{\text{thermal}} = 1 - \frac{1}{r_k^{\gamma-1}} \cdot \frac{r_{\text{cut off}}^{\gamma} - 1}{r_{\text{cut off}} - 1}$$

$$= 1 - \frac{1}{(1.4)(15)^{0.4}} \times \left(\frac{1.91^{1.4} - 1}{1.91 - 1} \right)$$

$$= 60.8\%$$

Qu. 14:



$$\text{Work} = Q_S - Q_R$$

$$W = C_V (T_3 - T_2) - C_V (T_4 - T_1)$$

$$= C_V [T_3 - T_2 - T_4 + T_1]$$

$$\frac{T_2}{T_1} = r_k^{\gamma-1}$$

$$\frac{T_3}{T_4} = r_k^{\gamma-1}$$

$$T_4 = T_3 r_k^{\gamma-1}$$

$$W = CV \left[T_3 - \frac{T_3}{\epsilon_k^{r-1}} - T_1 \epsilon_k + T_1 \right]$$

$$W = f(\epsilon_k)$$

$$\frac{dW}{d\epsilon_k} = -CV \cdot T_3 (1-r) \epsilon_k^{-r} - CV T_1 (r-1) \epsilon_k^{r-1} = 0$$

$$= -CV \cdot T_3 (1-r) \epsilon_k^{-r} = CV T_1 (r-1) \epsilon_k^{r-2}$$

$$\frac{T_3}{T_1} = \frac{\epsilon_k^{r-2}}{\epsilon_k^{-r}} = \epsilon_k^{2(r-1)}$$

$$\begin{aligned} (\epsilon_k)_{\text{optimum}} &= \left(\frac{T_3}{T_1} \right)^{\frac{1}{2(r-1)}} \\ &= \left(\frac{T_{\max}}{T_{\min}} \right)^{\frac{1}{2(r-1)}} \\ &= \left(\frac{T_{\min}}{T_{\max}} \right)^{\frac{1}{2(1-r)}} \end{aligned}$$

$$\begin{aligned} P_2 &= T_1 \epsilon_k^{r-1} \\ &= T_1 \left[\left(\frac{T_3}{T_1} \right)^{\frac{r-1}{2(r-1)}} \right]^{r-1} \end{aligned}$$

$$T_2 = \sqrt{T_1 T_3}$$

$$\begin{aligned} T_4 &= \frac{T_3}{(\epsilon_k)^{r-1}} \\ &= \frac{T_3}{\left[\left(\frac{T_3}{T_1} \right)^{\frac{r-1}{2(r-1)}} \right]^{r-1}} \\ &= \sqrt{T_1 T_3} \end{aligned}$$

When we operating at optimum work condition the temp at end of expansion = temp end of compression.

$$\text{and } T_2 = T_4 = \sqrt{T_1 T_3} \quad \text{--- (2)}$$

$k_{\max}$

$W_{\max}$

Q1.15

$$l_e = \frac{L}{2} +$$

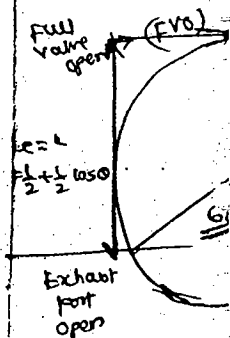
$$= 7 +$$

$$V_{se} = \frac{\pi}{4}$$

$$\epsilon_k =$$

$$\eta_{\text{thermal}} =$$

Q1.16: $l =$



$$\frac{q_{2320} V_1}{V_1 - V_1} \frac{1}{\sqrt{2}}$$

ratio

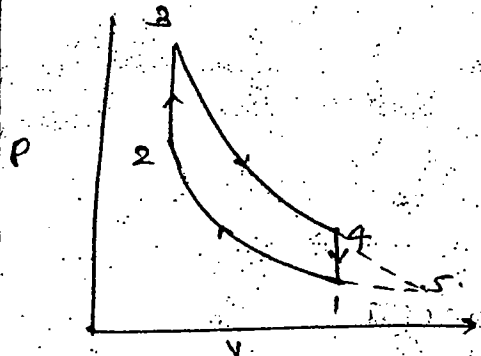
1.37

$$\frac{d\eta}{\eta} = -0.01367$$

$$\frac{d\eta}{\eta} \times 100 = -1.367\%$$

if cv increase by 2% efficiency decreases by 1.37%

pg. No. 29 Q. No. ①



$$\gamma_k = 6 = \frac{V_1}{V_2}$$

$$P_1 = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$T_1 = 27 + 273 = 300 \text{ K}$$

$$T_2 = 1545 + 273 = 1868 \text{ K}$$

$$P_4 = T_4 = ?$$

$$\gamma = 1.4$$

process 1-2

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\left(\frac{V_1}{V_2}\right)^\gamma = \frac{P_2}{P_1}$$

$$P_2 = 1228.603 \text{ kPa}$$

$$V_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 300}{100} = 0.861$$

$$V_2 = \frac{RT_2}{P_2} = 0.287 \times 1868$$

$$V_1 = 6 V_2$$

$$V_2 = 0.1425$$

$$V_2 = V_3$$

$$V_4 = V_1$$

process 3-4

$$P_3 V_3^\gamma = P_4 V_4^\gamma$$

$$\left(\frac{V_3}{V_4}\right)^\gamma = \frac{P_4}{P_3}$$

$$\left(\frac{0.1425}{0.861}\right)^{1.4} = \frac{P_4}{P_3}$$

$$P_3 = 8735.99$$

(1/6)

$$P_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$$

$$\left(\frac{V_3}{V_4} \right)^{\gamma-1} = \frac{T_4}{T_3}$$

$$\left(\frac{0.1425}{0.861} \right)^{0.4} = \frac{T_4}{T_3}$$

$$T_4 = 912.255 \text{ K}$$

for 4-1:

$$\frac{P_4}{T_4} = \frac{P_1}{T_1}$$

$$P_4 = \frac{100 \times 912.255}{300}$$

$$= 304.085$$

lowest possible pressure is 100 kPa

$$P_3 V_3^{\gamma} = P_5 V_5^{\gamma}$$

$$\left(\frac{V_3}{V_5} \right)^{\gamma} = \frac{P_5}{P_3}$$

$$\frac{V_3}{V_5} = \left(\frac{P_5}{P_3} \right)^{\frac{1}{\gamma}}$$

$$\frac{0.1425}{V_5} = \frac{100}{3325.99}$$

$$V_5 = 5.2611$$

$$r_E = \frac{V_5}{V_3} = 13.28$$

$$r_E = 13.28$$

$$\eta_{th} = 1 - \frac{(r_E^{\gamma} - r_k^{\gamma})}{r_E^{\gamma} - r_k^{\gamma}}$$

put the value of T_2 & T_4 in eqn ①

$$K_{\max} = C_v \left[T_3 - \sqrt{T_1 T_3} - \sqrt{T_1 T_3} + T_1 \right]$$

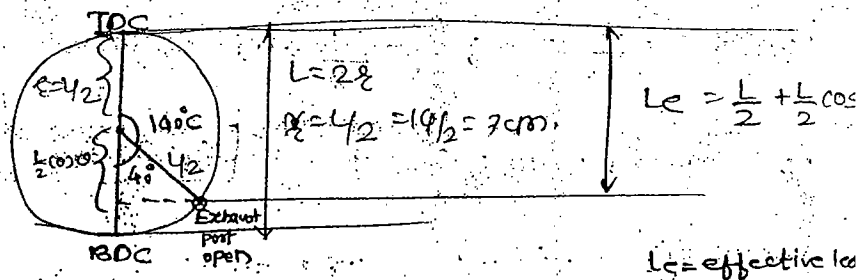
$$= C_v \left[T_3 + T_1 - 2\sqrt{T_1 T_3} \right]$$

$$K_{\max} = C_v \left[\sqrt{T_3} - \sqrt{T_1} \right]^2$$

Max workdone in Otto cycle

$$1-1 = 0$$

Q11.15



$$L_e = \frac{L}{2} + \frac{L}{2} \cos \theta = \text{effective stroke length}$$

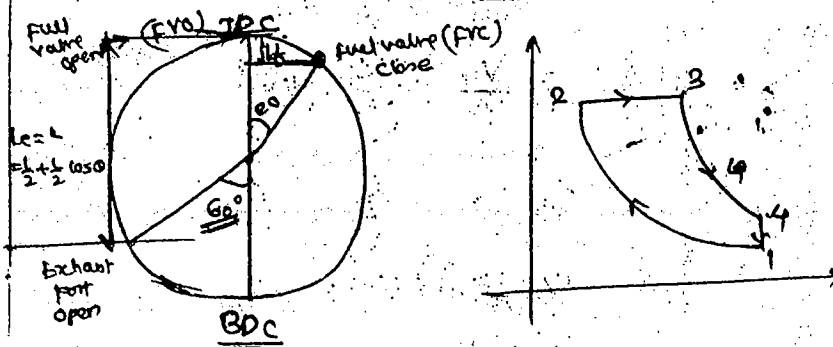
$$= 7 + 7 \cos 40^\circ = 12.36 \text{ cm}$$

$$V_{se} = \frac{\pi}{4} D^2 L_e = \frac{\pi}{4} \times 10^2 \times 12.36 = 970.7521 \text{ cm}^3 \text{ m.c.c.}$$

$$r_{ke} = \frac{V_{se} + V_c}{V_c} = \frac{970.75 + 157}{157} = 7.183$$

$$\eta_{\text{thermal}} = 1 - \left(\frac{1}{r_{ke}} \right)^{\gamma-1} = 1 - \left(\frac{1}{7.183} \right)^{0.4} = 54.55\%$$

Q11.16: $L = 14 \text{ cm}$, $D = 10 \text{ cm}$, $V_c = 40.2 \text{ cm}^3 \text{ m.c.c.}$



no condensation
compression.

$$\Rightarrow L_e = \frac{L}{2} + \frac{L}{2} \cos \theta = 7 + 7 \cos 60 = 10.5 \text{ cm}$$

$$\Rightarrow V_{\text{stroke effect}} = V_{se} = \frac{\pi}{4} D^2 L_e = \frac{\pi}{4} (10)^2 \times 10.5 = \underline{824.66 \text{ cm}^3}$$

$$\Rightarrow \epsilon_{\text{eff}} = \frac{V_{se} + V_c}{V_c} = \frac{824.66 + 40.2}{40.2} = \underline{21.5}$$

$$\Rightarrow L_f = \frac{L}{2} - \frac{L}{2} \cos \theta = 7 - 7 \cos 20 = 3.8 \text{ } \underline{0.422 \text{ cm}}$$

$$\Rightarrow (V_3 - V_2) = \frac{\pi}{4} D^2 L_f = \frac{\pi}{4} \times (10)^2 \times 0.422 = 33.14$$

$$V_3 = 40.2 + 33.14 = 73.34$$

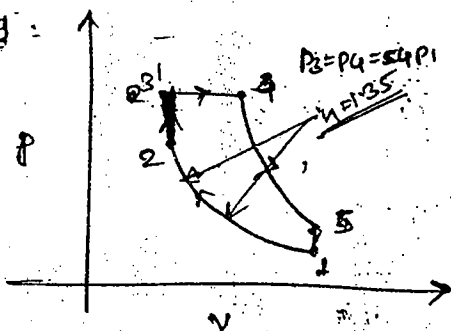
$$\boxed{V_3 = 73.34}$$

$$\epsilon_c = \frac{V_3}{V_2} = \frac{73.34}{40.2} = 1.82$$

ϵ_c = cut off ratio

$$\begin{aligned} (\eta_{\text{thermal}})_{\text{diesel}} &= 1 - \frac{1}{r \epsilon_c} \cdot \frac{\epsilon_c^r - 1}{\epsilon_c - 1} \\ &= 1 - \frac{1}{1.4 \times 21.5^{0.4}} \cdot \frac{1.82^{1.4} - 1}{1.82 - 1} \\ &= \underline{0.778} \end{aligned}$$

Q4.9 :



$$\epsilon_k = \frac{V_1}{V_2} = 12$$

$$\epsilon_c = \frac{V_4}{V_3} = \frac{V_4}{V_2} = 1.615$$

$$\epsilon_k = \epsilon_c \times \epsilon_E$$

$$12 = 1.615 \times \epsilon_E$$

$$\epsilon_E = \frac{12}{1.615} = 7.43 = \frac{V_5}{V_4} = \frac{V_1}{V_4}$$

low diff. eq

* Process 1-2

pv^{1.35} = c

$$P_1 V_1^n = P_2 V_2^n$$

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^n$$

$$= P_1 (12)^{1.35}$$

$$\boxed{P_2 = 28.63 P_1}$$

$$824.88 \text{ cm}^3$$

= cm

3-14

$$1W_2 = \frac{P_1 V_1 - P_2 V_2}{n-1} = \frac{P_1 V_1 - 28.63 P_1 \times \left(\frac{V_1}{12} \right)}{1.35-1}$$

$$1W_2 = -3.96 P_1 V_1$$

* 2-3

v=c

$$2W_3 = 0$$

* 3-4

p=c

$$3W_4 = P_4 (V_4 - V_3) = 54 P_1 (1.615 V_2 - V_2)$$

$$3W_4 = 54 P_1 (0.615 \times V_2) = 54 P_1 \left(0.615 \times \frac{V_1}{12} \right)$$

$$= 2.76 P_1 V_1$$

* 4-5

$$P_4 V_4^n = P_5 V_5^n$$

$$P_5 = P_4 \times \left(\frac{V_4}{V_5} \right)^n$$

$$= 54 P_1 \left[\frac{1}{7.93} \right]^{1.35}$$

$$= 9.84 \times 3.6 P_1$$

$$4W_5 = \frac{P_4 V_4 - P_5 V_5}{n-1} = \frac{54 P_1 \times 1.615 V_2 - 3.6 P_1 \times V_1}{1.35-1}$$

$$= \frac{54 P_1 \times 1.615 \frac{V_1}{12} - 3.6 P_1 V_1}{1.35-1} = 10.47 P_1 V_2$$

* 5-1

v=c

$$5W_1 = 0$$

$$W_{net} = 1W_2 + 2W_3 + 3W_4 + 4W_1 + 5W_1$$

$$= -3.96 P_1 V_1 + 0 + 2.76 P_1 V_1 + 10.47 + 0$$

$$= 9.27 P_1 V_1$$

$$= \frac{V_5}{V_4} = \frac{V_1}{V_4}$$

$$\eta = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} = \frac{9.277 \text{ kJ}}{12 \times 9.277 \text{ kJ}} = \frac{9.277 \text{ kJ}}{111.324 \text{ kJ}} = 0.0833$$

pg. NO 29 Q. 5 :

$$\frac{d\eta}{d\gamma} \times 100 = 2$$

$$\frac{d\eta}{d\gamma} = 0.02$$

$$\eta = 1 - \left(\frac{1}{r_k} \right)^{\gamma-1}$$

$$\eta = 1 - \left(\frac{1}{r_k} \right)^{\frac{R}{C_v}}$$

$$\log \eta = 1 -$$

$$\left(\frac{1}{r_k} \right)^{\frac{R}{C_v}} = 1 - \eta$$

$$1 - \eta = \left(\frac{1}{r_k} \right)^{\frac{R}{C_v}}$$

$$\ln(1 - \eta) = \frac{R}{C_v} \ln \left(\frac{1}{r_k} \right)$$

partial differentiation

$$\frac{1}{1 - \eta} d\eta = - \frac{R}{C_v} \frac{d\gamma}{\gamma^2} \ln \left(\frac{1}{r_k} \right)$$

$$- \frac{d\eta}{1 - \eta} = - \frac{R}{C_v} \frac{d\gamma}{\gamma^2} \ln \left(\frac{1}{r_k} \right)$$

$$d\eta = 1 - \eta \frac{R}{C_v} \frac{d\gamma}{\gamma^2} \ln \left(\frac{1}{r_k} \right)$$

divide by η

$$\frac{d\eta}{\eta} = \frac{1 - \eta}{\eta} \frac{R}{C_v} \frac{d\gamma}{\gamma^2} \ln \left(\frac{1}{r_k} \right)$$

$$\frac{d\eta}{\eta} = \frac{1 - 0.5116}{0.5116} \frac{0.287}{0.718} \times 0.02 \ln \left(\frac{1}{6} \right)$$

$r_k = \text{compression ratio}$

$$r_k = 6$$

$$\eta = 1 - \left(\frac{1}{r_k} \right)^{\gamma-1}$$

$$= 0.5116$$

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

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

pg. NO. 2



process

$$v_1 = \frac{R}{P_1}$$

$$v_2 = \frac{R}{P_2}$$

process

$$21 = \frac{1.4(13.28 - 6)}{13.28^{1.4} - 6^{1.4}}$$

$$= 59.36$$

5R

improvement in efficiency.

$$= \frac{59.36 - 51.1}{51.1} \times 100$$

$$= 16.16\%$$

pg. No 49 Q4.2 Ans (b)

pg. No 50 Q4.3

$$\text{fuel air ratio} = \frac{m_f}{m_a} = 0.05 = \frac{1}{20}$$

$$m_a = 20 \quad m_f = 1$$

$$\eta_{\text{volumetric}} = 0.9$$

$$\eta_v = \frac{m_a}{m_{\text{theoretical}}}$$

$$m_{\text{theoretical}} = \frac{20}{0.9} = \underline{\underline{22.22}}$$

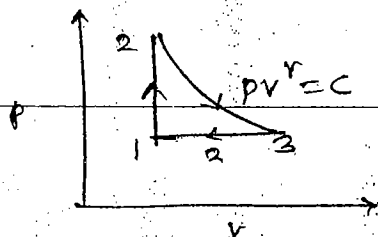
$$\text{Stroke volume } V_s = m_{\text{theoretical}} \times 1 = 22.22 \times 1 = 22$$

$$W = m_f \times c_v \times \eta_{th}$$

$$= 1 \times 45000 \times 0.3$$

$$= 13500 \text{ kJ}$$

$$m.e.p. = \frac{W}{V_s} = \frac{13500}{22.22} = \underline{\underline{607.56}}$$

process 1-2 $V=C$

$$Q_S = C_V(T_2 - T_1)$$

process 3-1 $P=C$

$$Q_R = C_P(T_3 - T_1)$$

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{C_P(T_3 - T_1)}{C_V(T_2 - T_1)}$$

$$= 1 - \frac{\gamma(T_3 - T_1)}{T_2 - T_1}$$

$$= 1 - \frac{C_P(T_3 - T_1)}{C_V(T_2 - T_1)}$$

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

process 1-2

$$\frac{P_2}{T_2} = \frac{P_1}{T_1}$$

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

process 3-1

$$= 1 - \gamma \left(\frac{V_3 - V_1}{V_2 - V_1} \right)$$

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

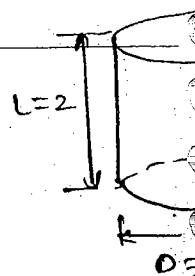
$$= 1 - \gamma \left(\frac{V_3 - V_1}{V_2 - V_1} \right)$$

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

$$\frac{V_1}{T_1} = \frac{V_3}{T_3}$$

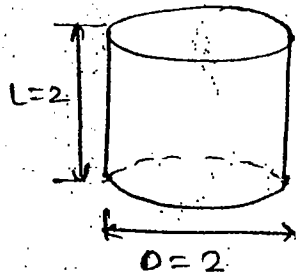
$$\frac{T_3}{T_1} = \frac{V_3}{V_1}$$

$$= 1 - \gamma \left(\frac{V_3 - V_1}{P_2 - P_1} \right) \times \frac{P_1}{V_1}$$

Ques 15

pg. No 29

Ques :



$$\text{Area} = 2 \times \frac{\pi}{4} \times D^2 + \pi D L$$

$$= 2 \times \frac{\pi}{4} \times (2)^2 + \pi \times 2 \times 2$$

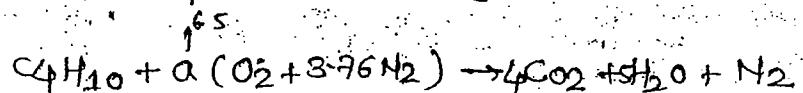
$$= 6\pi$$

$$\frac{v_1}{v_2} \times \frac{v_2}{v_1}$$

Butane is burned with stoichiometric air
determine the air fuel ratio

→ stoichiometric means chemically correct formula for air

In every 4.76 moles of air there is 1 mole of oxygen when a fuel is burned with chemically correct quantity of air the product of combustion of carbon dioxide water vapour and nitrogen



$$2a = 4 \times 2 + 5 \times 1$$

$$\downarrow$$

$$2444$$

$$a = 6.5$$

$$\text{(Air fuel ratio)}_{\text{chemically correct}} = \frac{m_a}{m_f}$$

$$= \frac{6.5 [2 \times 16 + 3.76 \times 28]}{4 \times 12 + 1 \times 10}$$

$$= 15.38$$

$$\text{(Fuel air ratio)} = \frac{m_f}{m_a}$$

$$= \frac{1}{15.38}$$

$$= 0.065$$

Butane is burned with 120% theoretical air :
 what is the partial pressure of water vapour in the exhaust products.

As per chemical eqn the product of combustion with excess air CO_2 , O_2 oxygen, water vapour and Nitrogen.

$$\begin{aligned} \text{Air fuel ratio} &= \frac{m_a}{m_f} \\ &= \frac{12.74 [2 \times 16 + 3.76 \times 28]}{133 \times 12 + 37.12 \times 1} \\ &= \underline{15.86} \end{aligned}$$

Relative fuel air ratio:

$$\phi = \frac{(\text{Fuel air ratio})_{\text{actual}}}{(\text{Fuel air ratio})_{\text{chemically correct}}}$$

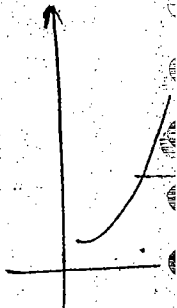
$\phi = 1$ — chemically correct mixture

$\phi > 1$ — Rich mixture

$\phi < 1$ — lean mixture

As per
Pa

Psychrom



partial
saturat
saturat
superhe
Humidit
It is
Specific
humidit

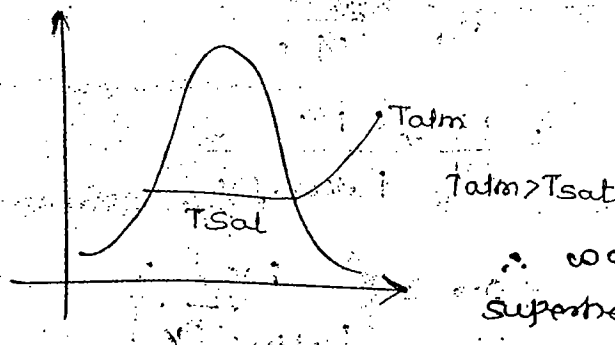
m

Psychrometry

As per Dalton's law of partial pressure

$$P_{air} + P_{vapor} = P_{atm}$$

Psychrometry is study of air vapor mixture



∴ water vapor present in superheated state corresponding

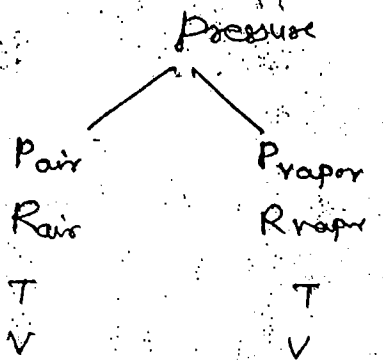
partial pressure of vapor whatever is the temp is called a saturation temp but the atm temp is greater than saturation temp hence the water vapor is present in superheated state and it is not visible to naked eye

Humidity ratio or specific humidity

It is ratio of mass of vapor to the mass of air

Specific humidity or (w) = $\frac{\text{mass of vapor}}{\text{mass of air}}$

humidity ratio



$$w = \frac{m_v}{m_a}$$

$$m_v = \frac{P_v \cdot V}{R_v \cdot T}$$

$$m_a = \frac{P_a \cdot V}{R_a \cdot T}$$

$$w = \frac{m_v}{m_a} = \frac{\frac{P_v \cdot V}{R_v \cdot T}}{\frac{P_a \cdot V}{R_a \cdot T}} = \frac{P_v}{P_a} \times \frac{R_a}{R_v}$$

degree

M

$$= \frac{P_v}{P_a} \times \frac{\frac{R}{M_a}}{\frac{R}{M_v}} = \frac{P_v}{P_a} \times \frac{M_v}{M_a}$$

$$= \frac{18}{29} \times \frac{P_v}{P_{atm} - P_v}$$

$$= 0.622 \left\{ \frac{P_v}{P_{atm} - P_v} \right\}$$

Relative humidity

The max amount of water vapor air can hold is called saturated mass if actual amount of water vapor is less than the saturated mass hence air is said to have relative humidity. Relative humidity is defined as the ratio of mass of vapor to the saturated mass.

$$\text{Relative humidity} (\phi) = \frac{m_{vap}}{m_{sat}} = \frac{m_v}{m_{sat}} = \frac{P_v}{P_{sat}}$$

when

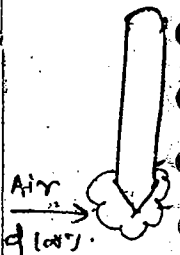
when

for

0 to 1

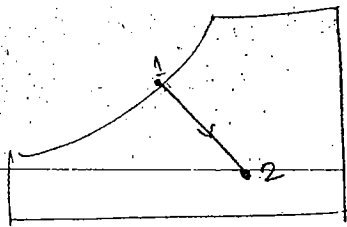
Dry

It is



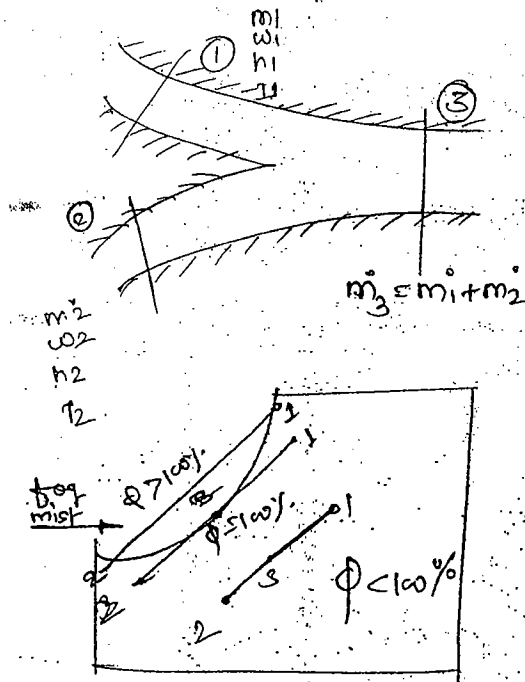
wet

if



DBT $\uparrow$ WBT $\rightarrow$ $h \rightarrow$
 $w \downarrow$ DPT $\downarrow$ RH $\downarrow$

Adiabatic mixing of two streams of air



high RH, high temp air
 mixes with high RH
 low temp air we may
 get situation of
 fog or mist
 $\phi > 100\%$

yellow light used penetrate fog in cold countries

As per mass balance

$$m_1 + m_2 = m_3$$

As per water balanced

$$m_1 w_1 + m_2 w_2 = m_3 w_3$$

$$= (m_1 + m_2) w_3$$

$$m_1 (w_1 - w_3) = m_2 (w_3 - w_2)$$

$$\frac{m_1}{m_2} = \frac{w_3 - w_2}{w_1 - w_3}$$

Energy balance

$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

$$= (m_1 + m_2) h_3$$

$$m_1 (h_1 - h_3) = m_2 (h_3 - h_2)$$

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}$$

At 28
 consid
 1.0218
 cubic
 flow
 Sens

Humid

LHL

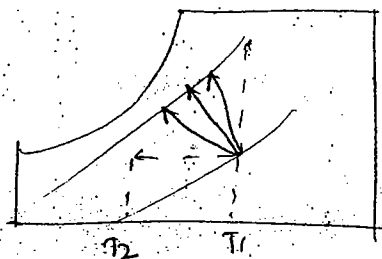
for air
 is to
 cool
 WBT $\uparrow$
 $\uparrow$

at

$h \downarrow$

→ Depending on curve

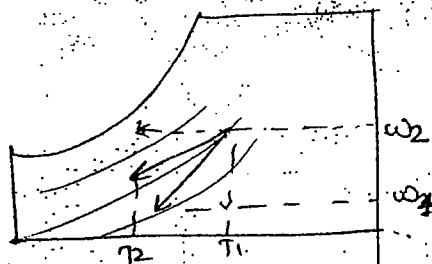
Cooling and humidification



The temp of H_2O spray in spray chamber should be $\geq$ Greater than DPT of air and should be less than DBT of air

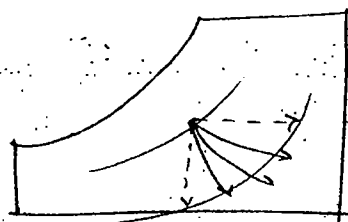
DBT $\downarrow$ WBT $\uparrow$ $h \uparrow$
 $w \uparrow$ DPT $\uparrow$ RH $\uparrow$

Cooling and dehumidification



DBT $\downarrow$ WBT $\downarrow$ $h \downarrow$ $w \downarrow$
 DPT $\downarrow$ RH $\downarrow$

Heating and dehumidification

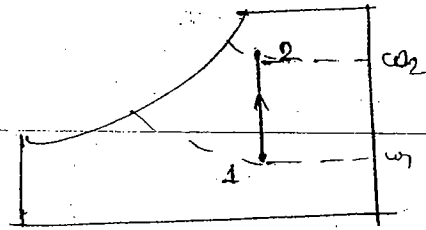


DBT $\uparrow$ WBT $\uparrow$ $h \uparrow$ $w \downarrow$
 DPT $\downarrow$ RH $\downarrow$

Chemical dehumidification process

by using a chemical a moisture present in air can removed and process is called chemical dehumidification by using hygroscopic material silica gel, H_2SO_4 , activated alumina, calcium hydroxide the water in vapor can be removed and process is called chemical dehumidification

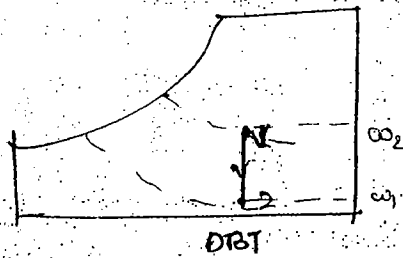
Humidification



Adding water vapor at constant DBT leads to humidification process

DBT is constant WBT $\uparrow$
 $h \uparrow$ $w \uparrow$ $DPT \uparrow$
 $RH \uparrow$

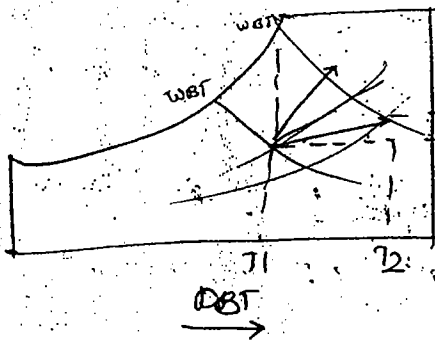
dehumidification



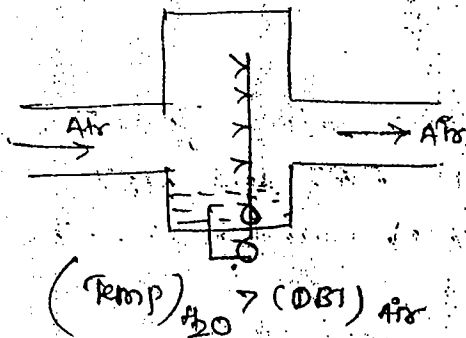
Removing water vapor at constant temp

DBT constant WBT $\downarrow$ $h \downarrow$
 $w \downarrow$ $DPT \downarrow$ $RH \downarrow$

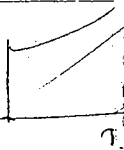
Heating and humidification



DBT $\uparrow$ WBT $\uparrow$ $h \uparrow$
 $w \uparrow$ $DPT \uparrow$ $RH \uparrow$ depending on curve



cooling



cooling



Heating



chemic

by
 can re
 cation
 activa
 can k

If $w = 0.011$ kg of vapor per kg of dry air determine the humid specific heat

$$c_{p,hs} = c_{p,a} + 1.88w$$

$$= 1.005 + 1.88 \times 0.011$$

$$= 1.025 \quad \text{--- humid specific heat}$$

Density of moist air

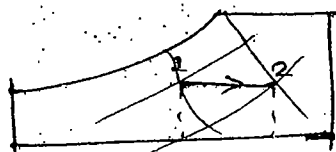
$$\rho_{\text{moist air}} = \rho_{\text{air}} + \rho_{\text{vapor}}$$

$$= \frac{p_a}{R_a T} + \frac{p_v}{R_v T}$$

$$= \frac{1}{T} \left[\frac{p_a}{R_a} + \frac{p_v}{R_v} \right]$$

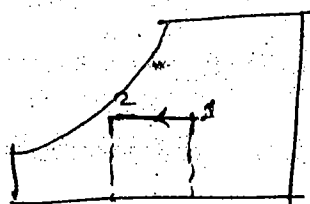
Psychrometric process

Sensible Heating



DBT $\uparrow$ WBT $\uparrow$ $h \uparrow$
 w constant DPT is constant
 $R \cdot h(\phi) \downarrow$

Sensible cooling



For sensible cooling final Temp. of air both DBT and DPT then only it called as Sensible cooling
 DBT $\downarrow$ WBT $\downarrow$ $h \downarrow$
 w constant DPT is constant
 $R \cdot h(\phi) \uparrow$

enthalpy of vapor
at 0°C

$$h_v = (h_{fg})_{0^\circ\text{C}} + c_{p_{\text{vapor}}} (T - 0)$$

if $w =$
the h

$c_{p_{hs}}$

at DPT

$$h_v = c_{p_{\text{liquid}}} (DPT - 0) + (h_{fg})_{DPT} + c_{p_{\text{vapor}}} (T - DPT)$$

Densit

Sensit
air

at T_{atm}

$$h_v = c_{p_l} (T_{\text{atm}} - 0) + (h_{fg})_{T_{\text{atm}}}$$

enthalpy of mixture

$$h = h_a + w h_v$$

Psychrom

$$= c_{p_a} (T - 0) + w \left((h_{fg})_{0^\circ\text{C}} + c_{p_v} (T - 0) \right)$$

Sensit

$$= (c_{p_a} + w c_{p_v}) (T - 0) + w (h_{fg})_{0^\circ\text{C}}$$

$h_s =$ humid
specific
heat

$$= c_{p_{hs}} (T - 0) + w (h_{fg})_{0^\circ\text{C}}$$

$$c_{p_{hs}} = c_{p_a} + w c_{p_v}$$

$$c_{p_{hs}} = c_{p_a} + 1.81w$$

$$= c_{p_a} + w c_{p_v} (T - 0) + w (2500)$$

$$= c_{p_{hs}} (T - 0) + 2500 w$$

Sensib

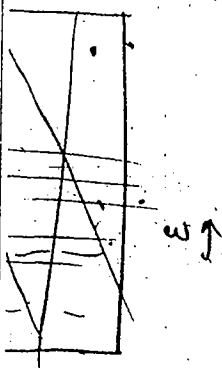
Ve...

DBT is

or present

air is

or condenses.



hant is

The curved lines on chart is called relative humidity curve. RH 100% line parallel is called decreasing R.

horizontal lines with uniform spacing are called as specific humidity lines.

with specific humidity lines meet RH 100% lines are get DPT

Dew point temp lines also horizontal lines with uniform spacing.

WBT lines are inclined lines sloping downward starting from RH 100% curves.

constant enthalpy lines are also inclined lines starting from RH 100% curve and sloping downwards.

technically speaking there is small deviation between WBT lines and enthalpy lines but the deviation is not very significant hence WBT lines and enthalpy lines are parallel lines for all practical purposes.

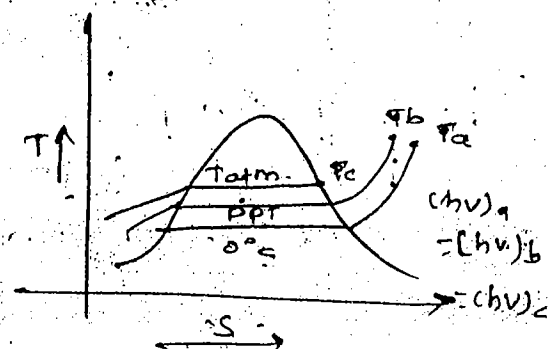
lines with higher inclination sloping downwards are constant specific volume line.

horizontal line with non uniform spacing on the psychrometric chart are called as vapor pressure lines.

enthalpy

$$h = h_{air} + w h_{vapor}$$

enthalpy of vapor can be defined with respect to 0°C with respect to Dew point & atm temp



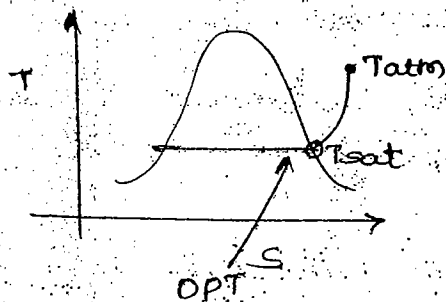
When ϕ of air is 0

Air cooler are used in places where DBT is very high and ϕ is very less

Dew point temp

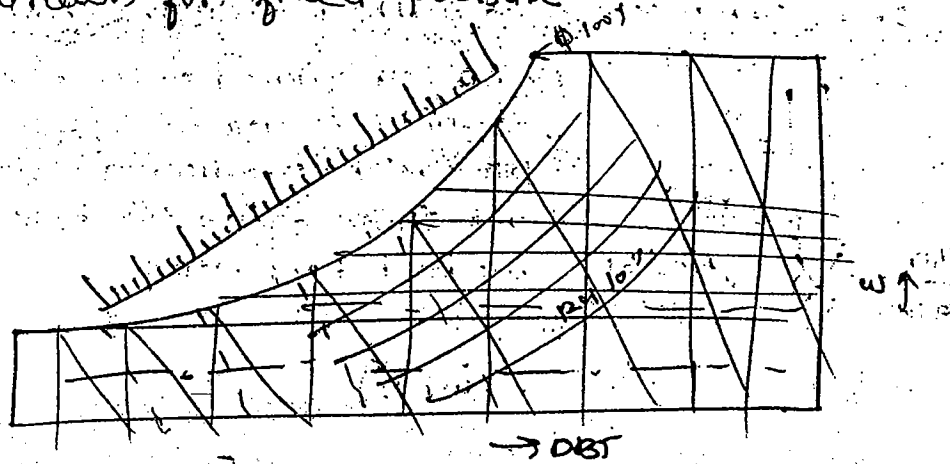
The temp. at which the water vapor present in air start condensing. if temp of air is equal to saturation temp then water vapor condenses which is called as dew point temp

at $\phi = 100\% \rightarrow \text{DBT} = \text{WBT} = \text{DPT}$



Psychrometric chart

It is drawn for fixed pressure



vertical line with uniform spacing in chart is called as DBT lines.

the curve
curved line
horizontal
specific

with sp
get DPT
Dew point
spacing.

WBT line
from RH 10

constant
from RH

feels
between

is not w
lines are

lines
constant

had
the pr
lines

enthalpy

$h =$

enthalpy

be defid

0°C wet

point

$$\times \frac{R_a}{R_y}$$

$\frac{P_v}{P}$

can
of amount
ed mass
humidity
ratio of

$\frac{P_v}{P}$
sat

Degree of saturation (M)

$$M = \frac{W}{W_{sat}} = 0.622 \cdot \frac{P_v}{P_{atm} - P_v}$$

$$= 0.622 \cdot \frac{P_{sat}}{P_{atm} - P_{sat}}$$

$$= \frac{P_v (P_{atm} - P_{sat})}{P_{sat} (P_{atm} - P_v)}$$

$$= \phi \left[\frac{P_{atm} - P_{sat}}{P_{atm} - P_v} \right]$$

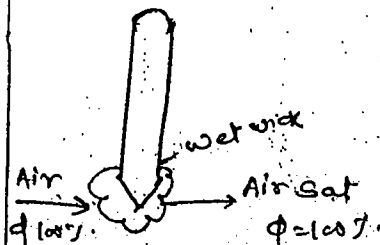
when $M=0$ ϕ is 0%.

when $M=1$ ϕ is 100%.

For other values of M relative humidity is between 0 to 100%.

Dry bulb temperature

It is temp recorded with a ordinary thermometer



When unsaturated air is blown on or wet wick evaporation of water take place which produced a cooling effect and temp drops this temp is called wet bulb temperature

Wet bulb depression (WBD)

$$WBD = DBT - WBT$$

if WBD is 0 then DBT = WBT and ϕ is 100%.

$$h_f \Rightarrow (ADP)_{Temp}$$

ADP = Apparatus dew point

Apply SFEE:

ad (TAL)

$$\dot{m}_a h_1 - \dot{Q} = \dot{m}_a h_2 + \dot{m}_f h_f$$

$$\dot{m}_a h_1 - \dot{Q} = \dot{m}_a h_2 + \dot{m}_a (\omega_1 - \omega_2) h_f$$

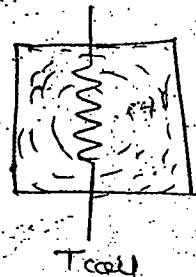
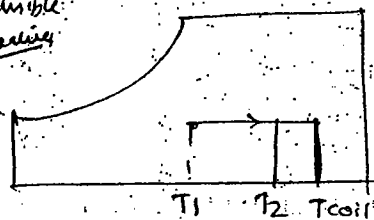
tr (SAF)

$$\dot{Q} = \dot{m}_a (h_1 - h_2) - \dot{m}_a (\omega_1 - \omega_2) h_f$$

$$SHL = \dot{m}_a (h_3 - h_2)$$

1-2 - cooling and dehumidification process is ideal process it is never practical because of bypass air as result ~~same~~ bypass factor.

Sensible heating



BP

Bypass factor $BPF = \frac{T_{coil} - T_2}{T_{coil} - T_1}$

BPF depend upon velocity in chamber. The velocity is temp is becoming less and BPF is higher.

If velocity of air is less temp is becoming high BPF is less

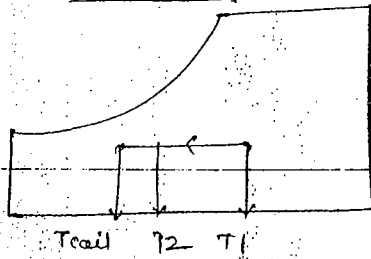
contact factor (C.F.) $\frac{T_2 - T_1}{T_{coil} - T_1}$

coming out air coil as 9

equal to mp or the point temp

$$\text{Contact factor} + BPF = 1$$

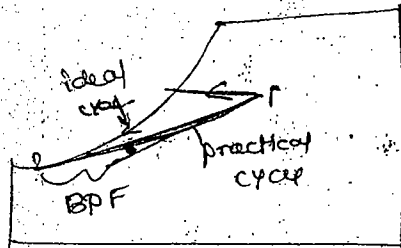
Psychrometric Chart



$$BPF = \frac{T_2 - T_{coil}}{T_1 - T_{coil}}$$

$$CF = \frac{T_1 - T_2}{T_1 - T_{coil}}$$

cooling and dehumidification



$$BPF = \frac{h_c - h_2}{h_1 - h_2}$$

$$= \frac{w_c - w_2}{w_1 - w_2}$$

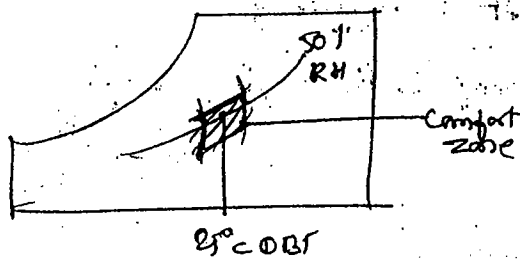
$$= \frac{T_c - T_2}{T_1 - T_2}$$

Summer air conditioning is cooling and dehumidification followed by sensible cooling heating.

comfort conditions are

$$DBT = 22^\circ C$$

$$RH = 50\%$$



Wintex

Supplying of hot H₂O



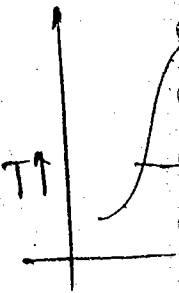
Heating

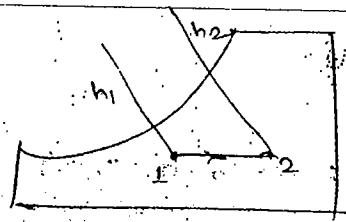


m

m

Adiabatic





Sensible heat load (kW)

$$= \dot{m}_a (h_2 - h_1)$$

$$= \dot{m}_a \cdot c_{p,hs} (T_2 - T_1)$$

$$= \dot{m}_a (C_{p,a} + \omega c_{p,v}) (T_2 - T_1)$$

At 20°C DBT and P.H 50% the density of air considered as 1.2 kg/m³ and $C_{p,hs}$ is considered as 1.0216 kJ/kg. the flow rate of air measured as 1 cubic meter per minute

$$\boxed{\text{flow rate of air} = \dot{V} \text{ Gmm}}$$

$$\text{Sensible heat load (SHL)} = \dot{m}_a c_{p,hs} (T_2 - T_1)$$

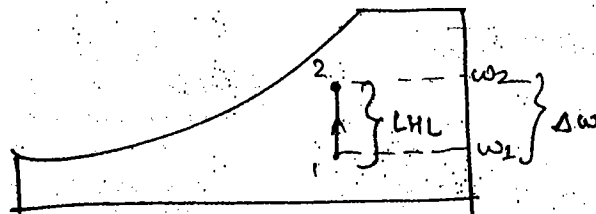
$$= \frac{\dot{V}}{60} \cdot c_{p,hs} (T_2 - T_1)$$

$$= \frac{\dot{V}}{60} \times 1.2 \times 1.0216 (\Delta T)$$

$$= 0.0204 \dot{V} (\Delta T) \text{ kW}$$

Humidification process

LHL: latent heat load



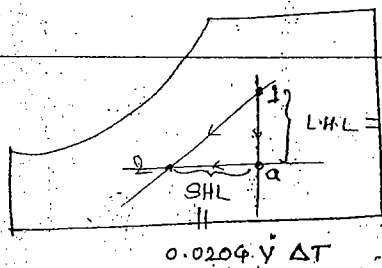
$$\text{LHL (kW)} = \dot{m}_a (\omega_2 - \omega_1) (h_{f,g})_{0^\circ\text{C}}$$

$$= \frac{1.2}{60} \times 2500 \times \dot{V} \Delta \omega$$

$$= 50 \dot{V} \Delta \omega$$

Cooling and dehumidification

It is an summer air conditioning process



Total heat load (THL)

$$LHL = 50 \dot{V} \Delta \omega = SHL + LHL$$

Sensible heat factor (SHF)

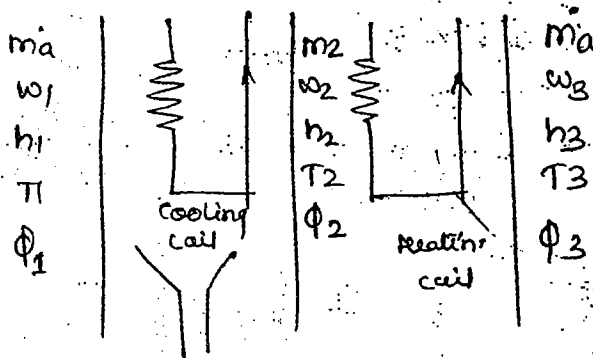
$$SHF = \frac{SHL}{SHL + LHL}$$

$$SHF = \frac{0.0204 \dot{V} \Delta T}{0.0204 \dot{V} \Delta T + 50 \dot{V} \Delta \omega}$$

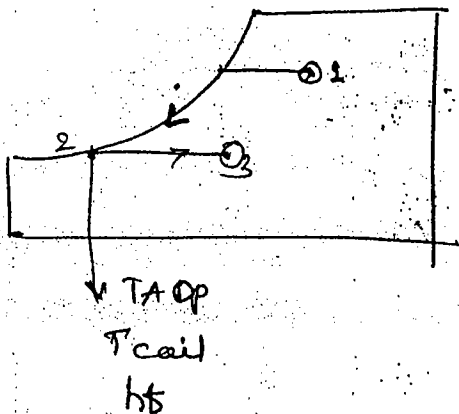
$$SHF = \frac{SHL}{THL}$$

$$= \frac{1}{1 + \frac{50}{0.0204} \left(\frac{\Delta \omega}{\Delta T} \right)} = \frac{1}{1 + 2451 \left(\frac{\Delta \omega}{\Delta T} \right)}$$

Cooling and dehumidification



$$m_f = m_a (w_1 - w_2)$$



h_f = water coming out from air coil as enthalpy equal to the coil temp or the apparatus dew point temp

$\eta_f \Rightarrow$

Apply SFH

$\dot{m}_{a1}$

$\dot{m}_{a1}$

$\dot{Q} =$

SHL =

1-2 - co

pr

air

Sensible heat



BP

Bypass

BPF d

temp is

If rel

BPF

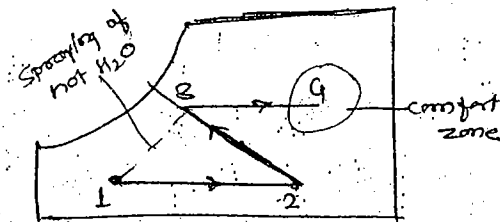
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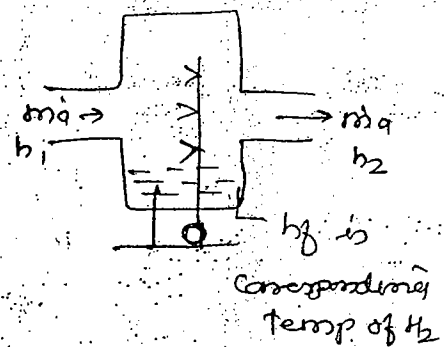
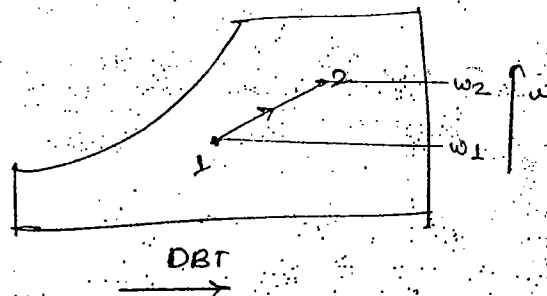
Conte

Winter air conditioning

1-3 is process
substitute for 1-2 to 2-3



Heating and humidification

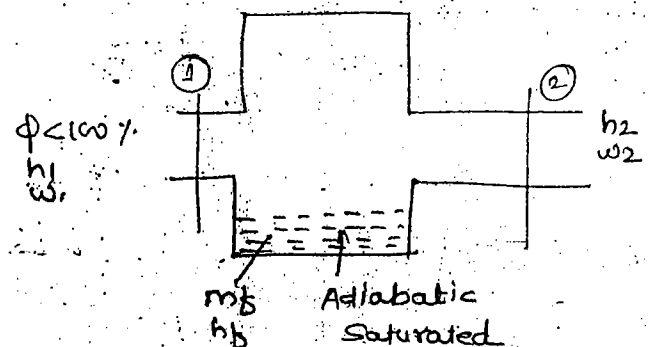


$$\dot{m}_a h_1 + \dot{m}_f h_f = \dot{m}_a h_2$$

$$\dot{m}_a h_1 + \dot{m}_a (\omega_2 - \omega_1) h_f = \dot{m}_a h_2$$

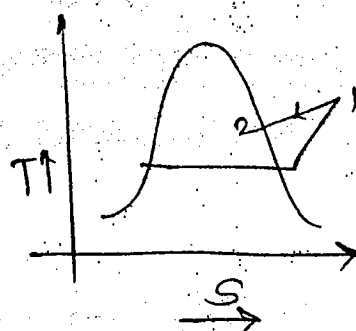
humidification

Adiabatic saturation process



$$\dot{m}_f = \dot{m}_a (\omega_2 - \omega_1)$$

1-2 $\Rightarrow$ Adiabatic saturation process



Adiabatic saturation temp & WBT are same for air vapor mixtures. for other gas vapor mixture adiabatic saturation temp and wet bulb temp are different

problems: pg No 32 Q.1

$$T = 20^{\circ}\text{C} \quad P_{\text{sat}} = 2.337 \text{ kPa}$$

$$\phi = \frac{P_v}{P_{\text{sat}}}$$

$$0.7 = \frac{P_v}{2.337}$$

$$P_v = 2.337 \times 0.7 = 1.636 \text{ kPa}$$

$$w = 0.622 \frac{P_v}{P_{\text{atm}} - P_v}$$

$$= 0.622 \times \frac{1.636}{101.325 - 1.636} = 0.0102 \frac{\text{kg vapor}}{\text{kg of dry air}}$$

Q.1.2

$$T = 25^{\circ}\text{C} \quad P_{\text{sat}} = 3.166 \text{ kPa}$$

$$\phi = \frac{P_v}{P_{\text{sat}}}$$

$$0.74 = \frac{P_v}{3.166}$$

$$P_v = 0.74 \times 3.166$$

$$= 2.34 \quad \therefore \rightarrow T_{\text{sat}} = 20^{\circ}\text{C}$$

$$w = 0.622 \frac{P_v}{P_{\text{atm}} - P_v}$$

$$= 0.622 \times \frac{2.34}{101.325 - 2.34}$$

$$= 0.0147 \frac{\text{kg vap}}{\text{kg dry air}}$$

If the
start so
for 6.5 K
SK
5
6.5

cloud 2

②

④

h₁

w₁

φ₁

T₁

P_{sat}

φ₁

0.8

P_{v1}

Tem

for air
adiabatic
process

If the T_{atm} drops from 25°C to 20°C then cloud form
start so dropping temp. $dT = 5^\circ\text{C} \approx 5\text{K}$

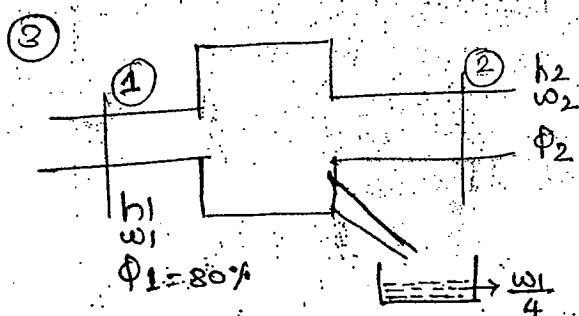
for $6.5\text{K} \rightarrow 1000\text{m}$

$5\text{K} \rightarrow ?$

$$\frac{5}{6.5} \times 1000 = \underline{770\text{m}}$$

cloud formation start at 770m

6 kPa



$$\phi_1 = 80\%$$

$$T_1 = 20^\circ\text{C}$$

$$P_{\text{sat}} = 2.337\text{ kPa}$$

$$\phi_1 = \frac{P_{V1}}{P_{\text{sat}}}$$

$$0.8 = \frac{P_{V1}}{2.337}$$

$$P_{V1} = 1.87$$

$$w_1 = 0.622 \frac{P_{V1}}{P_{\text{atm}} - P_{V1}}$$

$$= 0.622 \frac{1.87}{100 - 1.87}$$

$$= 0.0185 \frac{\text{kg vap}}{\text{kg dry air}}$$

$$w_2 = \frac{2w_1}{4}$$

$$= \frac{3 \times 0.0185}{4}$$

$$= 0.622 \frac{P_{V2}}{P_{\text{atm}} - P_{V2}}$$

$$\frac{3 \times 0.0185}{4} = 0.622 \frac{P_{V2}}{100 - P_{V2}}$$

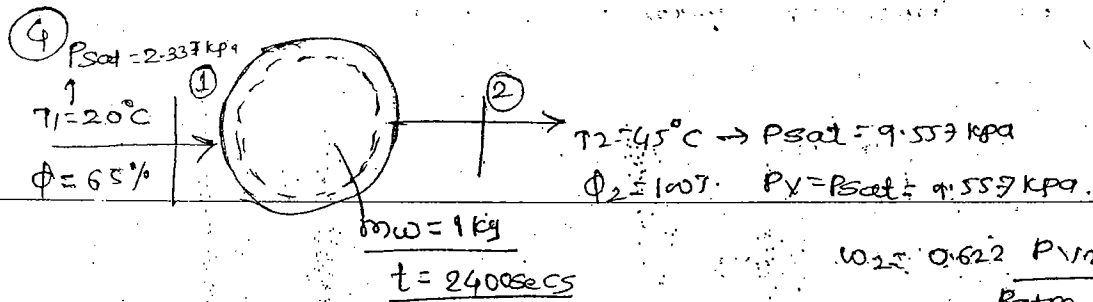
$$P_{V2} = 12.41 \rightarrow 1.41\text{ kPa}$$

$$T_2 = 12^\circ\text{C}$$

Temp of air leaving the dehumidifier is 12°C

vapor
of dry air

°C



$$\phi_1 = \frac{P_v}{P_{sat}}$$

$$0.65 = \frac{P_v}{2.337}$$

$$P_v = 1.52$$

$$w_1 = 0.622 \frac{P_{v1}}{P_{atm} - P_{v1}}$$

$$= 0.622 \times \frac{1.52}{100 - 1.52}$$

$$= 0.0096 \frac{\text{kg vap}}{\text{kg dry air}}$$

$$w_2 = 0.622 \frac{P_{v2}}{P_{atm} - P_{v2}}$$

$$= 0.622 \times \frac{9.557}{100 - 9.557}$$

$$= 0.0657 \frac{\text{kg vap}}{\text{kg dry air}}$$

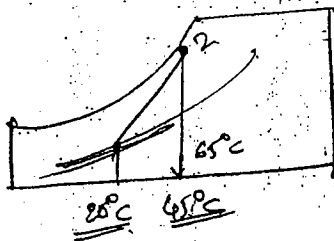
$$\dot{m}_a (w_2 - w_1) = \frac{\dot{m}_w}{t}$$

$$\dot{m}_a (0.0657 - 0.0096) = \frac{1}{2400}$$

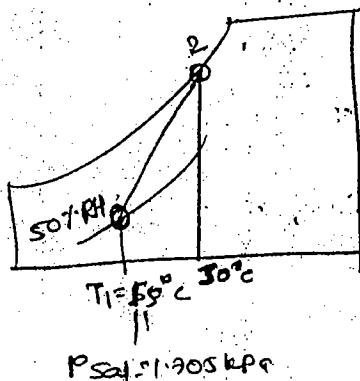
$$\dot{m}_a = 0.00242 \text{ kg/sec}$$

$$= 0.00242 \times 3600$$

$$= 8.712 \text{ kg/hr}$$



⑤



$$\phi = \frac{P_v}{P_{sat}}$$

$$0.5 = \frac{P_v}{1.905}$$

$$P_v = 0.8525 \text{ kPa}$$

$$w_1 = 0.622 \frac{P_{v1}}{P_{atm} - P_{v1}}$$

$$w_1 = \dots$$

$$= 0.15$$

$$T_2 = 30^\circ\text{C}$$

$$P_{sat} = \dots$$

$$\phi = \dots$$

$$P_v = \dots$$

Amount of

$$= \dot{m}_a$$

$$= 12.15$$

$$= 0.266$$

$$= 0.266$$

$$= 9.58$$

⑥

$$h_1 = 32 \frac{\text{kJ}}{\text{kg}}$$

$T_{coil} = T_{ADP} = 11^\circ\text{C}$
 (Chf)

$$\dot{m}_a$$



$$\begin{aligned}
 &1.553 \text{ kPa} \\
 &= 9.553 \text{ kPa} \\
 &= 0.622 \frac{P_{v12}}{P_{atm} - P_{v12}} \\
 &= \frac{0.622 \times 9.553}{100 - 9.553} \\
 &= 0.0657 \frac{\text{kg vap}}{\text{kg dry air}}
 \end{aligned}$$

$$\begin{aligned}
 w_1 &= \frac{0.622 \times 0.8525}{101.325 - 0.8525} \\
 &= 0.00529 \frac{\text{kg vap}}{\text{kg of dry air}}
 \end{aligned}$$

$$T_2 = 30^\circ\text{C}$$

$$P_{\text{sat}} = 4.241 \text{ kPa}$$

$$\phi = \frac{P_v}{P_{\text{sat}}}$$

$$P_v = 4.241 \text{ kPa}$$

$$\begin{aligned}
 w_2 &= 0.622 \frac{P_{v2}}{P_{atm} - P_{v2}} \\
 &= 0.622 \times \frac{4.241}{101.325 - 4.241}
 \end{aligned}$$

$$= 0.0272 \frac{\text{kg vap}}{\text{kg of dry air}}$$

$$m_a = \frac{P_v}{RT} = \frac{P_a}{R_a} \cdot \frac{y}{T}$$

$$= \frac{(101.325 - 0.8525)}{0.287 \times 288}$$

$$= 12.155 \text{ kg/sec}$$

Amount of H_2O vapor removed

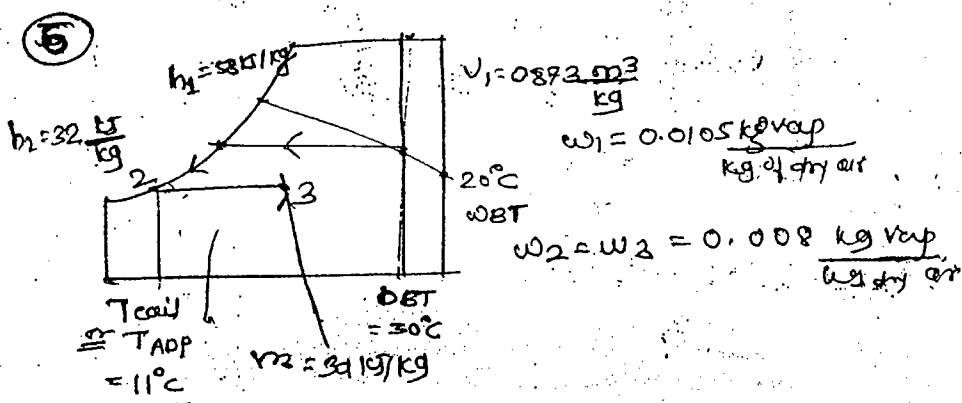
$$= m_a (w_2 - w_1)$$

$$= 12.15 (0.0272 - 0.00529)$$

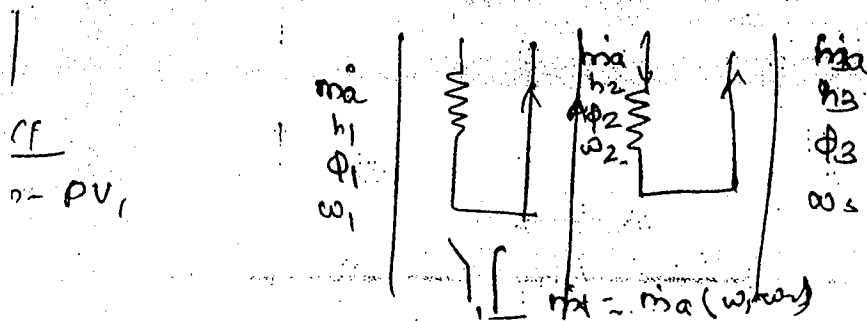
$$= 0.2662 \text{ kg/sec}$$

$$= 0.2662 \times 3600 \text{ kg/hr}$$

$$= 958.32 \text{ kg/hr}$$



$$C_{h_f} \text{ at } T_{\text{app}} = 46.21 \text{ kJ/kg}$$



$$\dot{m}_f = \dot{m}_a (\omega_1 - \omega_2)$$

$$h_f = 46.2 \text{ kJ/kg}$$

Apply STEE

$$\dot{m}_a h_1 + \dot{m}_f h_f = \dot{m}_a h_2$$

$$\dot{m}_a h_1 + \dot{m}_a (\omega_1 - \omega_2) h_f =$$

$$\dot{m}_a h_1 - \dot{Q} = \dot{m}_a h_2 + \dot{m}_f h_f$$

$$= \dot{m}_a h_2 + \dot{m}_a (\omega_1 - \omega_2) h_f$$

$$\omega_{\text{sat}} =$$

$$\dot{V} = 200 \frac{\text{m}^3}{\text{min}}$$

$$\dot{m} = \frac{\dot{V}}{v_1} = \frac{200}{60} \times \frac{1}{0.873} = 3.82 \text{ kg/sec}$$

$$3.82 \times 58 - \dot{Q} = 3.82 \times 32 + 3.82 [0.0105 - 0.008] 46.2$$

$$\dot{Q} = 98.87 \text{ kW}$$

$$\text{SHL (kW)} = \dot{m}_a (h_3 - h_2)$$

$$= 3.82 (39 - 32)$$

$$= 26.74 \text{ kW}$$

Q.7

$$\ln p = 19.013 - \frac{5325}{T}$$

$$P_{\text{atm}} = 960 \times 10^{-3} \times 10^2$$

$$= 96 \text{ kPa}$$

$$\text{Temp} = 30^\circ \text{C}$$

$$\phi = 60\%$$

$$\ln P_{\text{sat}} = 19.013 - \frac{5325}{303}$$

$$P_{\text{sat}} = 4.1253 \text{ kPa}$$

$$\phi = \frac{p}{P_{\text{sat}}}$$

$$0.6 = \frac{p}{4.1253}$$

$$p = 2.47518 \text{ kPa}$$

Degree of

The term
as dew

enthalpy

$$\phi = \frac{P_v}{P_{sat}}$$

$$\omega = 0.622 \frac{P_v}{P_{atm} - P_v}$$

$$0.6 = \frac{P_v}{4.215}$$

$$= 0.622 \frac{2.53}{96 - 2.53}$$

$$P_v = 2.525 \text{ kPa}$$

$$= 0.0168 \frac{\text{kg vap}}{\text{kg dry air}}$$

+ m_f h_f

+ m_a (w₁ - w₂) h_f

$$\omega_{sat} = 0.622 \frac{P_{sat}}{P_{atm} - P_{sat}}$$

$$= 0.622 \times \frac{4.215}{96 - 4.215}$$

$$= 0.0285 \frac{\text{kg vap}}{\text{kg of dry air}}$$

sec

$$0.008 \times 46.2$$

$$\text{Degree of Saturation } \mu = \frac{\omega}{\omega_{sat}} = \frac{0.0168}{0.0285} = 0.58$$

The temp corresponding partial pressure in air is call as dew point temp

$$\ln P_v = 19.013 - \frac{5325}{DPT}$$

$$\ln 2.53 = 19.013 - \frac{5325}{DPT}$$

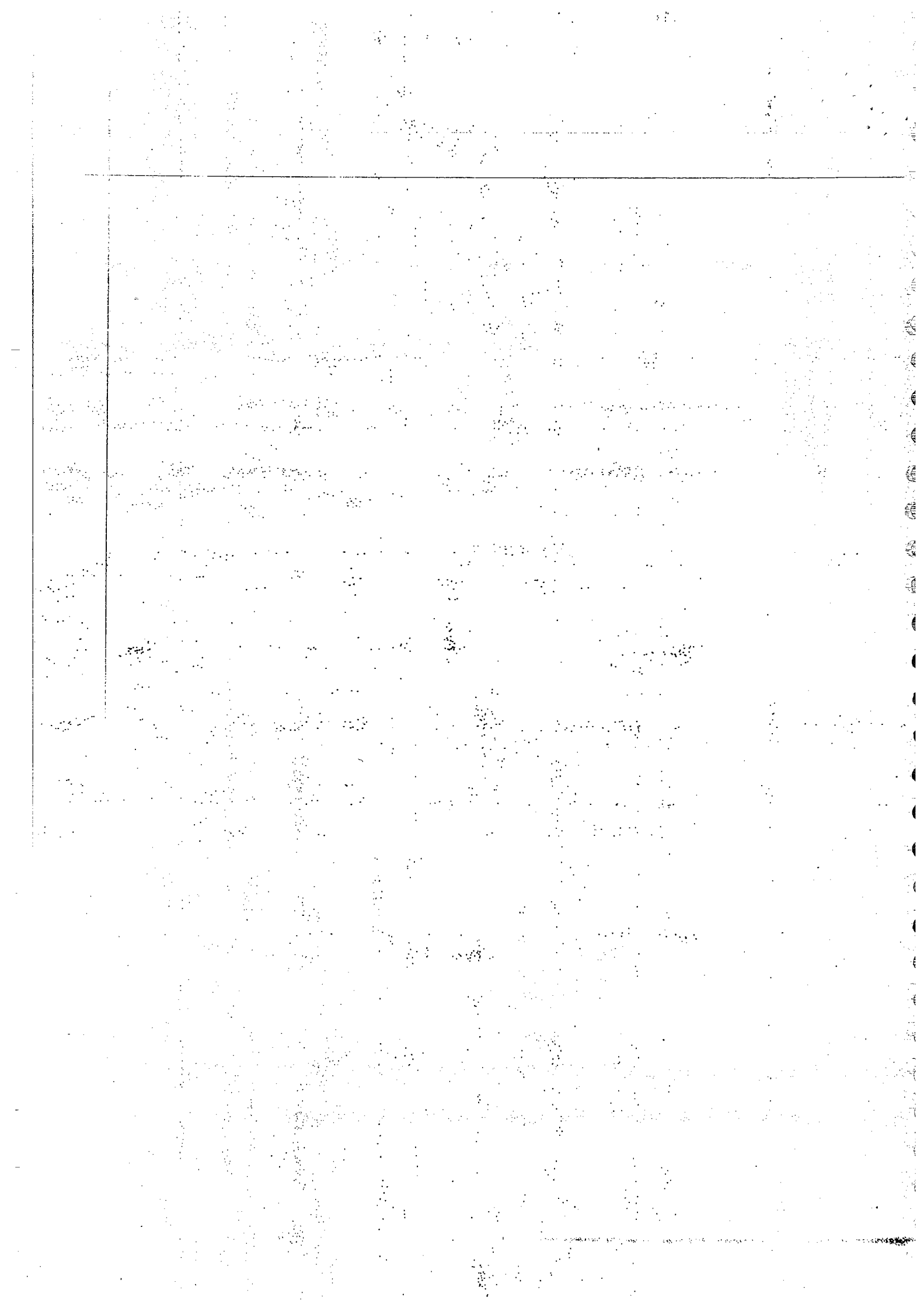
$$DPT = 294.44 \text{ K} \text{ or } 21.44^\circ\text{C}$$

enthalpy stream $C_{p,air}$

$$h = C_{p,a}(T - 0) + \omega (h_{fg} + C_{p,v}(T - 0))$$

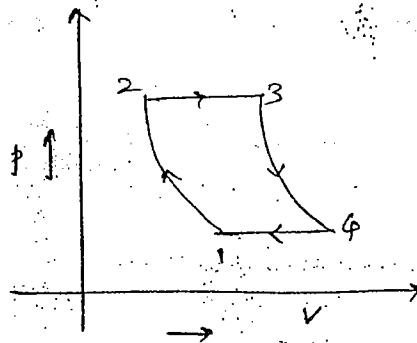
$$= 1(30 - 0) + 0.0168 (2514 + 1.88(30 - 0))$$

$$= 73.18 \text{ kJ/kg of dry air}$$



GAS TURBINE

Joule cycle or Brayton cycle



1-2 $\Rightarrow$ Reversible Adiabatic compression

2-3 $\Rightarrow$ constant pressure heat supply

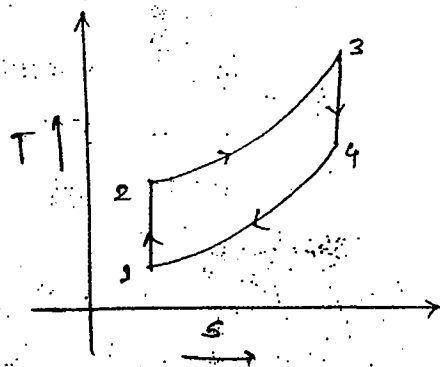
3-4 $\Rightarrow$ Reversible Adiabatic expansion

4-1 $\Rightarrow$ cp heat rejection

$$\text{Compression ratio} = r_c = \frac{V_1}{V_2}$$

$$\text{Expansion ratio} = r_e = \frac{V_4}{V_3}$$

$$\text{pressure ratio} = r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$



1-2 $\Rightarrow$ Reversible Adiabatic compression

$Q=0$ $s = \text{constant}$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^{\gamma} = P_1 r_c^{\gamma} \quad \text{--- (1)}$$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1} = T_1 r_c^{\gamma-1} \quad \text{--- (2)}$$

$$T_1 P_1^{\frac{1-\gamma}{\gamma}} = T_2 P_2^{\frac{1-\gamma}{\gamma}}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (3)}$$

$$W_2 = \frac{\gamma}{\gamma-1} [P_1 V_1 - P_2 V_2]$$

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

$$= m \cdot c_p (T_1 - T_2) \quad \text{--- (4)}$$

$$= m \cdot (h_1 - h_2) \quad \text{--- (5)}$$

2-3 $p = \text{const}$ $\rightarrow$ isobaric

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$T_3 = \frac{V_3}{V_2} \times T_2 \quad \text{--- (6)}$$

$$2. Q_3 = C_p (T_3 - T_2) \quad \text{--- (7)}$$

3-4 Reversible Adiabatic Expansion

$$Q = 0 \quad S = C$$

$$P_3 V_3^r = P_4 V_4^r$$

$$P_3 = P_4 \left(\frac{V_4}{V_3} \right)^r$$

$$= P_4 \left(\frac{1}{r_E} \right)^r \quad \text{--- (8)}$$

$$P_3 V_3^{r-1} = P_4 V_4^{r-1}$$

$$P_3 = P_4 \left(\frac{V_4}{V_3} \right)^{r-1}$$

$$= P_4 \left(\frac{1}{r_E} \right)^{r-1} \quad \text{--- (9)}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4} \right)^{\frac{r-1}{r}} \quad \text{--- (10)}$$

$$Q_{43} = \frac{r}{r-1} (P_3 V_3 - P_4 V_4)$$

$$= \frac{r}{r-1} m R (T_3 - T_4) \quad \text{--- (11)}$$

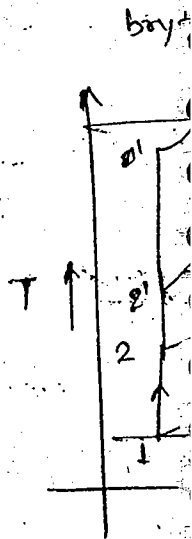
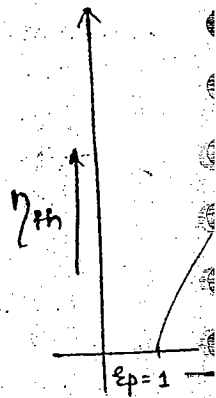
$$= m (h_3 - h_4) \quad \text{--- (12)}$$

4-1 $p = \text{const}$ heat rejection

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

$$T_4 = \frac{V_4}{V_1} \times T_1 \quad \text{--- (13)}$$

Thermal



$$4Q_1 = C_p(T_4 - T_1) \quad \text{--- (19)}$$

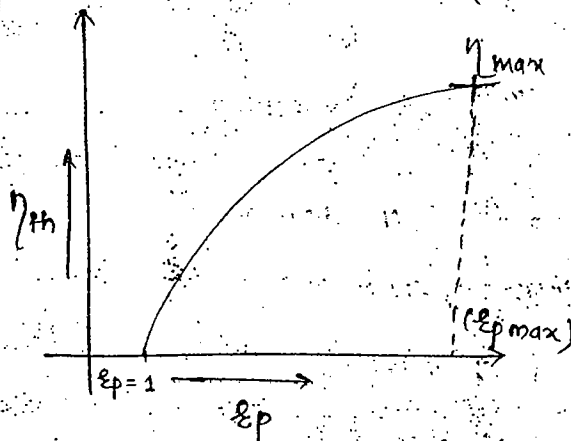
Thermal efficiency =

$$\eta_{th} = 1 - \frac{Q_R}{Q_S}$$

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

$$= 1 - \left(\frac{1}{\epsilon_p}\right)^{\frac{\gamma-1}{\gamma}} = f(\epsilon_p, \gamma)$$

$$= 1 - \left(\frac{1}{\epsilon_k}\right)^{\gamma} = f(\epsilon_k, \gamma)$$



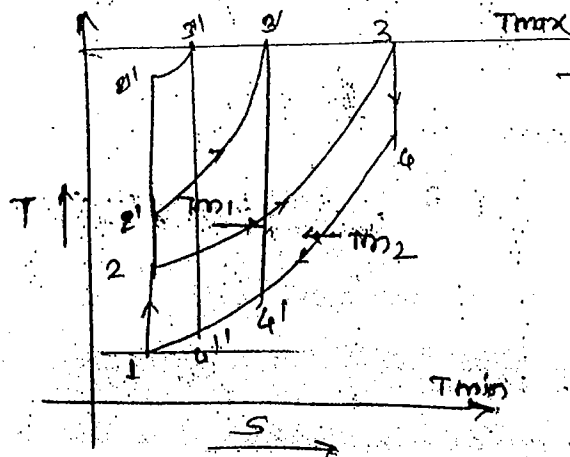
The Max efficiency of any cycle is Carnot efficiency

$$\eta_{th} = 1 - \left(\frac{1}{\epsilon_{p_{max}}}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 1 - \left(\frac{T_{min}}{T_{max}}\right)$$

$$\epsilon_{p_{max}} = \left[\frac{T_{max}}{T_{min}} \right]^{\frac{\gamma}{\gamma-1}}$$

At the above pressure ratio the η_{th} of the brayton cycle is maximum



T_{m1} = Mean temp of heat supply

$$= \frac{h_3 - h_2}{s_3 - s_2}$$

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

T_{m2} = Mean temp of heat rejected

$$= \frac{h_4 - h_1}{s_4 - s_1} = \frac{c_p (T_4 - T_1)}{c_p \ln \frac{T_4}{T_1}} = \frac{T_4 - T_1}{\ln \frac{T_4}{T_1}}$$

$$\eta_{th} = 1 - \frac{Q_R}{Q_S}$$

$$= 1 - \left(\frac{h_4 - h_1}{h_3 - h_2} \right)$$

$$= 1 - \frac{T_{m2} (s_4 - s_1)}{T_{m1} (s_3 - s_2)}$$

$$= 1 - \frac{T_{m2}}{T_{m1}} \Rightarrow f(T_{m1}, T_{m2})$$

T_{m1} constant T_{m2} constant increases η_{th} decreases

T_{m1} constant T_{m2} decreases η_{th} increases

T_{m2} constant T_{m1} increases η_{th} increases

T_{m2} constant T_{m1} decreases η_{th} decreases

T_{m1} decreases η_{th} decreases T_{m1} increases η_{th} increases

T_{m2} increases η_{th} decreases T_{m2} decreases η_{th} increases

ϵ_p increases T_{m1} increases

ϵ_p increases T_{m2} decreases

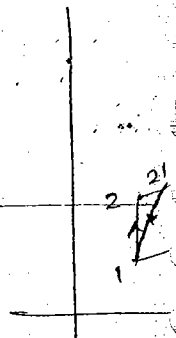
ϵ_p increases $T_{m1} \rightarrow T_{m2}$

ϵ_p increases $T_{m2} \rightarrow T_{m1}$

$$(\eta_{th})_{\text{Brayton}} \geq (\eta_{th})_{\text{Carnot}}$$

when we operating at higher pressure ratios
expansion work is almost equal to compression work.

and net work availability is less through the efficiency is
maximum and net work availability less will not be
operating at pressure ratios



In older
the range
very less

Now a

hence th

Gas turb

Work expa

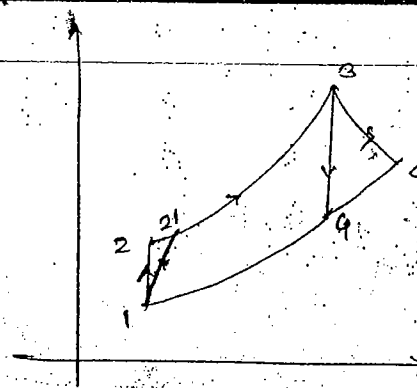
Work comp

back to

expansion

back

Work &



1-2 $\Rightarrow$ isentropic compression

1-2' $\Rightarrow$ Actual compression

$$\eta_{\text{compressor}} = \frac{\text{Work isentropic}}{\text{Work Actual}}$$

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

$$1 = \frac{T_2 - T_1}{T_2' - T_1}$$

$$T_2' =$$

$$\eta_{\text{turbine}} = \frac{C_p (T_3 - T_4')}{C_p (T_3 - T_4)}$$

$$T_4' = T_3 - \eta_{\text{turbine}} (T_3 - T_4)$$

as

on

In older days the compressor turbine efficiency are the range of 60 to 70% hence the cycle efficiency are very less and Gas turbine are not popular in 1920

Now a days compressor turbine efficiency are greater than hence the η_{thermal} improved to 27% now a days.

η_{th} increasing

Gas turbine are very popular

η_{th} increases

$$\text{Work}_{\text{expansion}} = C_p (T_3 - T_4)$$

$$\text{Work}_{\text{compressor}} = C_p (T_2 - T_1)$$

or Compressor

back work ratio defined as ratio of compressor work expansion work

$$\text{back work ratio} = \frac{W_C}{W_E} = \frac{C_p (T_2 - T_1)}{C_p (T_3 - T_4)} = \frac{T_2 - T_1}{T_3 - T_4}$$

ratio

work

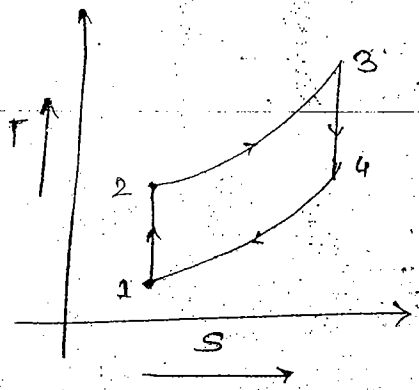
the efficiency is not be

$$\text{Work ratio} = \frac{W_{\text{net}}}{W_E}$$

$$= \frac{W_E - W_C}{W_E} = 1 - \frac{W_C}{W_E} = 1 - \frac{C_p (T_2 - T_1)}{C_p (T_3 - T_4)}$$

Optimum workdone in Gas turbine cycle

when
temp e



$$K = Q_S - Q_R$$

$$K = c_p(T_3 - T_2) - c_p(T_4 - T_1)$$

$$= c_p(T_3 - T_2 - T_4 + T_1)$$

$$\frac{T_2}{T_1} = \epsilon_p^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_3}{T_4} = \epsilon_p^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 \epsilon_p^{\frac{\gamma-1}{\gamma}}$$

$$T_4 = \frac{T_3}{\epsilon_p^{\frac{\gamma-1}{\gamma}}}$$

$$K = c_p \left(T_3 - T_1 \epsilon_p^{\frac{\gamma-1}{\gamma}} - \frac{T_3}{\epsilon_p^{\frac{\gamma-1}{\gamma}}} + T_1 \right) = f(\epsilon_p)$$

$$\frac{dK}{d\epsilon_p} = -c_p T_1 \left(\frac{\gamma-1}{\gamma} \right) \epsilon_p^{\frac{\gamma-1}{\gamma} - 1} - c_p T_3 \left(\frac{1-\gamma}{\gamma} \right) \epsilon_p^{\frac{1-\gamma}{\gamma} - 1} = 0$$

$$(\epsilon_p)_{\text{optimum}} = \left(\frac{T_3}{T_1} \right)^{\frac{\gamma}{2(\gamma-1)}} = \left(\frac{T_{\text{max}}}{T_{\text{min}}} \right)^{\frac{\gamma}{2(\gamma-1)}}$$

$$\boxed{\frac{dK}{d\epsilon_p} = \sqrt{(\epsilon_p)_{\text{max}}}}$$

$$T_2 = T_1 \epsilon_p^{\frac{\gamma-1}{\gamma}}$$

$$= T_1 \left[\left(\frac{T_3}{T_1} \right)^{\frac{\gamma}{2(\gamma-1)}} \right]^{\frac{\gamma-1}{\gamma}} = \sqrt{T_1 T_3}$$

$$T_4 = \frac{T_3}{(\epsilon_p)^{\frac{\gamma-1}{\gamma}}}$$

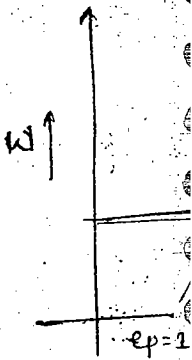
$$= \frac{T_3}{\left[\left(\frac{T_3}{T_1} \right)^{\frac{\gamma}{2(\gamma-1)}} \right]^{\frac{\gamma-1}{\gamma}}}$$

T_2

work K_{net}

At opti

γ



open cy



the system
plate is
for air

When cycle is operating at optimum pressure ratio the temp end of expansion equal to temp end of comp

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

$$W_{\text{or } K_{\text{max}}} = C_p [T_3 - \sqrt{T_1 T_3} - \sqrt{T_1 T_3} + T_1]$$

$$= C_p [\sqrt{T_3} - \sqrt{T_1}]^2$$

At optimum pressure ratio

$$\eta_{th} = 1 - \sqrt{\frac{T_{min}}{T_{max}}}$$

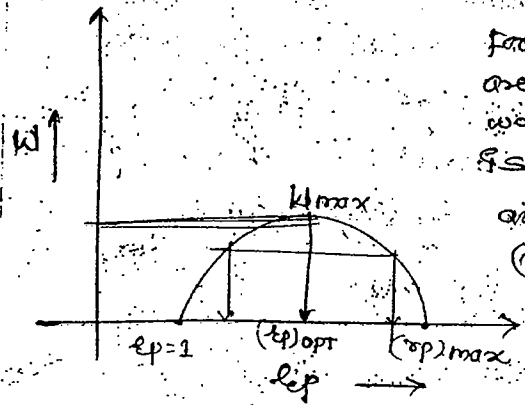
$$\epsilon_p \frac{\gamma-1}{\gamma}$$

$$\frac{T_3}{T_1} \frac{\gamma-1}{\gamma}$$

ϵ_p

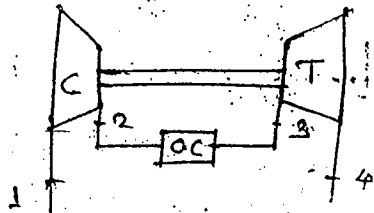
$$\frac{1-\gamma}{\gamma} - 1 = 0$$

$$2(\gamma-1)$$



For work less than max work there are two pressure ratios at which the work is same. One pressure ratio is between ϵ_{p1} and $\epsilon_{p \text{ optimum}}$ another pressure ratio is in between $(\epsilon_p)_{\text{optimum}}$ and $(\epsilon_p)_{\text{maximum}}$.

open cycle gas turbine



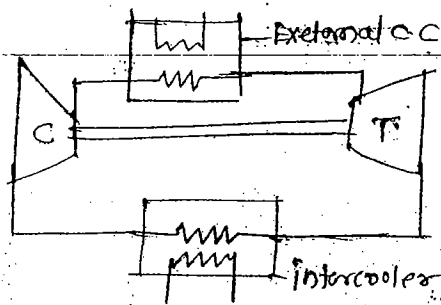
every time fresh air is sucked from atmosphere it is combusted in the combustion chamber and it is exhausted turbine

In the compressor only air is flow in the turbine Air + fuel is flow hence the mass flowing through turbine is greater than mass flow through the compressor.

As dust particle are entering the system the wear and tear compressor plate & turbine plate is very high. it is light in weight hence it is used for aircraft engine.

Closed cycle gas turbine

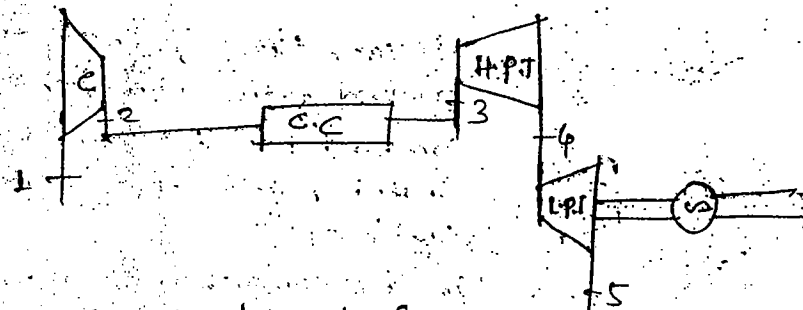
CCGT closed cycle Gas turbine plant



here external combustion chamber is used as it is external combustion chamber any type of fuel can be used. In closed cycle any type of medium can be used

If the medium is helium which is having higher ratio of specific heat the thermal efficiency will be high here the intercooler is used to cool the hot gases coming out of turbine. two extra H.E are used hence weight is high and cost is high C.C.G.T are generally used in nuclear power plant. As the weight is high they cannot be used in aircraft engines

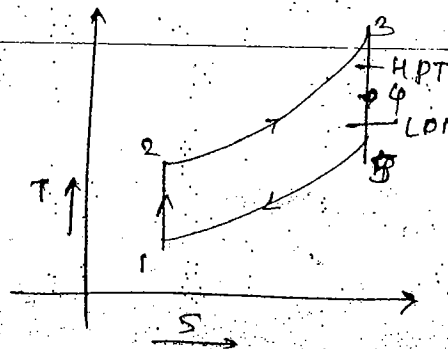
Free shaft turbine



here compressor load and Generator load are separated the work output on high pressure turbine is used to operate compressor. while work output of L.P.T is used to operate generator

As the compressor load and Generator load are separated it respond to part load operation.

all combustion
used as it
combustion
ry type of
used in
ry type of
be used
is helium
e thermal
d to cool the
are used
are
the weight
gives



$$(W_{\text{work}})_{\text{comp}} = W_{\text{HPT}}$$

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

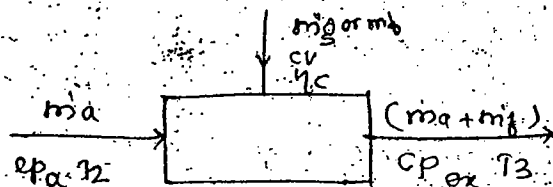
$$(W)_{\text{LPT}} = C_p(T_4 - T_5) = \text{Generator Load,}$$

This is used for part load operation

$$\frac{P_2}{P_1} = \frac{P_3}{P_4} \times \frac{P_4}{P_5}$$

$$(\eta_p)_{\text{comp}} = (\eta_p)_{\text{HPT}} \times (\eta_p)_{\text{LPT}}$$

open cycle combustion chamber



$$\dot{m}_a c_{p,a} T_2 + \dot{m}_f (c_{p,f}) \eta_c = (\dot{m}_a + \dot{m}_f) c_{p,ex} T_3$$

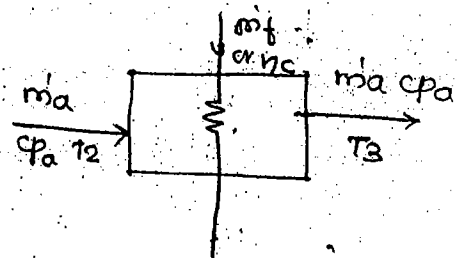
$$\frac{\dot{m}_a}{\dot{m}_f} \cdot c_{p,a} T_2 + (c_{p,f}) \eta_c = \left(\frac{\dot{m}_a}{\dot{m}_f} + 1 \right) \cdot c_{p,ex} T_3$$

$$(\text{Air fuel ratio}) c_{p,a} T_2 + (c_{p,f}) \eta_c = (\text{AFR} + 1) c_{p,ex} T_3$$

separated
used to
is used to

Generator
compressor

Closed cycle combustion chamber



$$\dot{m}_a c_{p,a} T_2 + \dot{m}_f (c_{p,f}) \eta_c = \dot{m}_a \cdot c_{p,a} T_3$$

$$\frac{m_a}{m_f} \cdot c_{pa} T_2 + (c_v) \eta_c = \frac{m_a}{m_f} c_{pa} T_3$$

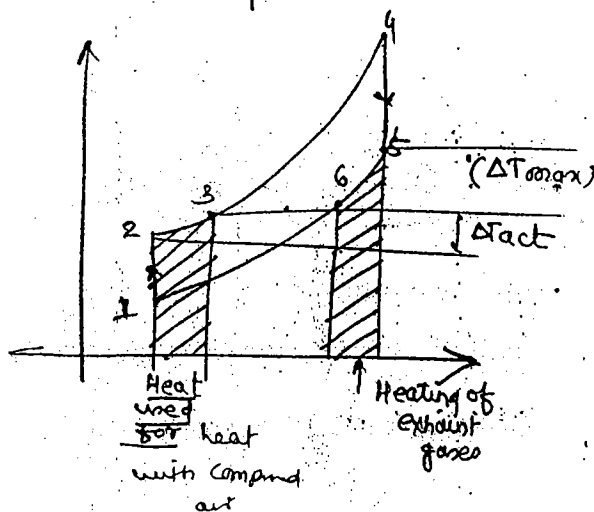
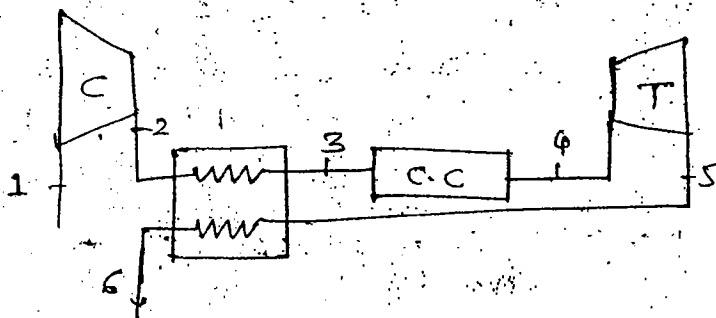
$$(A.F.R)_{cpa} T_2 + (c_v) \eta_c = A.F.R \cdot c_{pa} \cdot T_3$$

Methods for improving thermal efficiency of Gas turbine cycle

- ① Method of Regeneration
- ② Method of Reheating
- ③ Method of Intercooling

Method of Regeneration

In this method the heat of exhaust gases is used to heat the compressed air as a result air enters the combustion chamber at a higher temp and consequently the amount of fuel burned will be less hence thermal efficiency improves.



Effectiveness of H.E

$$e = \frac{(\Delta T)_{act}}{(\Delta T)_{max}}$$

$$e = \frac{T_3 - T_2}{T_5 - T_2}$$

KT as CC
Qs dec
Tm1 ↑

Afr rate

Heat supply

Heat reject

$(\eta_{th})_{ideal}$
rege

@ (rp) cr
 η_{ideal}
Regene

1- Tmin
Tmax

$\epsilon_{pc} =$

$\epsilon_{pc} =$

At $\epsilon_p = 1$

η_{ideal}
rege

greater H
bryton ef
ideal reg
principle
not effe
pressure
critical

k_f is constant k_c is constant k_{net} is constant

Q_s decreases

$$T_{m1} \uparrow \quad T_{m2} \downarrow \quad \eta_{th} \uparrow$$

Air rate remain constant and heat rate decreases

Heat supplied $Q_s = h_4 - h_3$

Heat rejected $Q_R = h_6 - h_1$

$$(\eta_{th})_{\text{ideal regenerative cycle}} = 1 - \frac{T_{min}}{T_{max}} \cdot \epsilon_p^{\frac{r-1}{r}}$$

$$= 1 - \frac{T_1}{T_4} \epsilon_p^{\frac{r-1}{r}}$$

@ (r_p) critical

$$\eta_{\text{ideal regenerative}} = \eta_{\text{bryton}}$$

$$1 - \frac{T_{min}}{T_{max}} (\epsilon_{pc})^{\frac{r-1}{r}} = 1 - \left(\frac{1}{\epsilon_{pc}} \right)^{\frac{r-1}{r}}$$

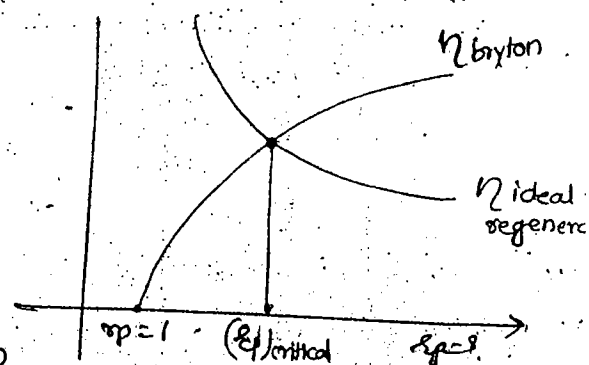
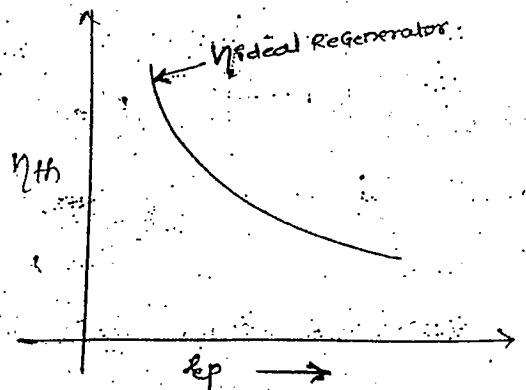
$$\epsilon_{pc} = \left[\frac{T_{max}}{T_{min}} \right]^{\frac{r}{2(r-1)}}$$

$$\epsilon_{pc} = \sqrt{(r_p)_{max}}$$

At $\epsilon_p = 1$ and $\epsilon_p = \text{critical}$

$$\eta_{\text{ideal regenerative}} > \eta_{\text{bryton}}$$

greater than ϵ_p critical
bryton efficiency is greater than
ideal regenerative hence the
principle of regeneration is
not effective when the
pressure ratio is greater than
critical pressure ratio



@ (r_p) critical $\eta_{\text{bryton}} = \eta_{\text{ideal regenerative}}$

of

is
out
r temp
will be

of H.E

back

max

- T₂

- T₂

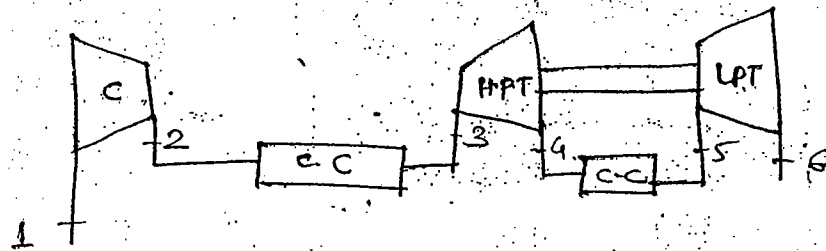
If pressure ratio is greater than γ critical, the air at end of compression is greater than temp end of exhaust hence instead of air being heated up gets cooled in the H.E and consequently thermal efficiency falls. don't use regeneration beyond (γ) critical

only reheat
reheating
 η_{th} of cycle

Method of Reheating

In this the heating is done in two stages stage 1 and stage 2 and expands as done in two turbine

Method
Instead
with inter

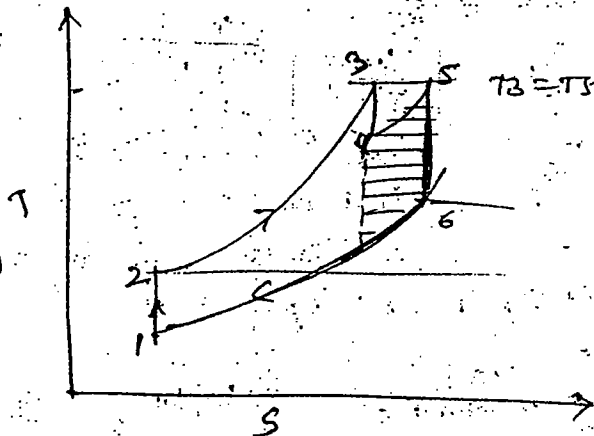


$$W_T = (h_3 - h_4) + (h_5 - h_6)$$

$$W_C = (h_2 - h_1)$$

$$Q_S = c_p (T_3 - T_2) + c_p (T_5 - T_4)$$

$$Q_R = c_p (T_6 - T_1)$$



$AR = \text{Air rate}$
 $HR = \text{Heat rate}$

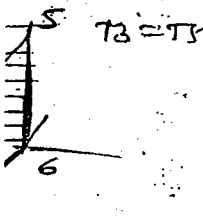
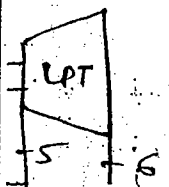
Turbine work increases when compared to simple cycle
Net work increases W_C is same Q_S increases $Q_R \uparrow$

$A_R \downarrow$ $\eta_{th} \downarrow$ $\rightarrow$ Air rate (A_R) $\downarrow$ Heat rate $\uparrow$

Turbine exhaust temp increases. The gap of turbine exhaust temp increases

the temp
end of
up gets
efficiency
heat

has
done in

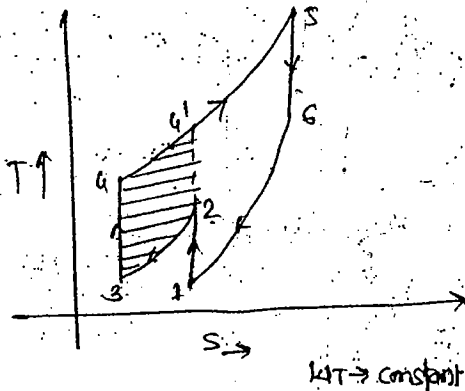
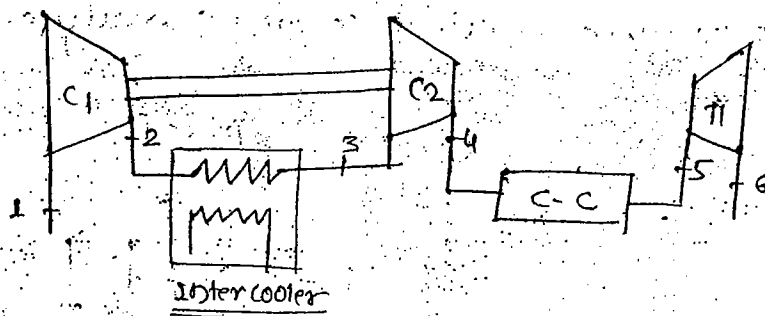


→
nple cycle
QR ↑
te ↑
bine

- the principle of regeneration can be applied here
- only reheating will reduce η_{th} of the cycle. but reheating and regeneration will always improved the η_{th} of cycle

Method of intercooling: (Intercooled cycle)

Instead of single stage compression, multistage compression with intercooling adopted to improved the η_{th} of cycle



AR = Air rate
HR = Heat rate

$$kT = h_5 - h_6$$

$$kC = (h_2 - h_1) + (h_4 - h_3)$$

$$Q_S = h_5 - h_4$$

$$Q_R = (h_6 - h_1) + (h_2 - h_3)$$

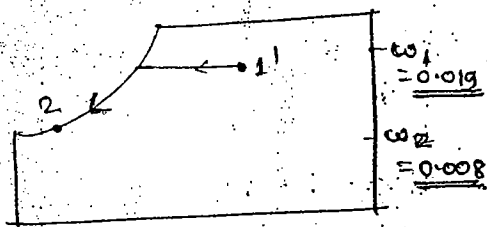
WT → kC ↓ kT ↑ Q_S ↑
 η_{th} ↓ T_{m1} ↓ T_{m2} ↑ AR ↓ HR

The gap between Turbine exhaust & compressor exist increase consequently and hence principle of regeneration can be employed. only intercooling reducing η_{th} of cycle but intercooling and regeneration will always improve η_{th} of cycle.

Psychrometry

Atm air at a flow rate of 3 kg/s on dry basis enters a cooling and dehumidifying coil with an enthalpy of 85 kJ/kg of dry air and humidity ratio of 19 gms/kg of dry air the air leaves the coil with an enthalpy of 43 kJ/kg of dry air and a humidity ratio of 8 gms/kg of dry air the condensate water leaves the coil with an enthalpy of 67 kJ/kg - the required cooling capacity coil in kW is

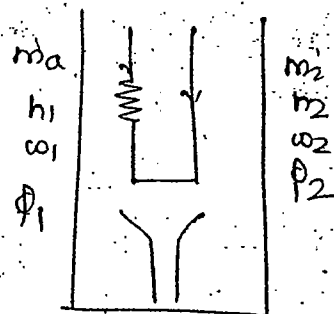
- (a) 75 (b) 123.8 (c) 128.2 (d) 159



$$h_1 = 85 \text{ kJ/kg}$$

$$h_2 = 43 \text{ kJ/kg}$$

$$h_f = 67 \text{ kJ/kg}$$



$$\dot{m}_f = \dot{m}_a (w_1 - w_2)$$

$$h_f$$

Apply SFEE

$$\dot{m}_a h_1 - \dot{Q} = \dot{m}_a h_2 + \dot{m}_f h_f$$

$$= \dot{m}_a h_2 + \dot{m}_a (w_1 - w_2) h_f$$

$$\dot{Q} = \dot{m}_a (h_1 - h_2) - \dot{m}_a (w_1 - w_2) h_f$$

$$= 3(85 - 43) - 3(0.019 - 0.008) 67$$

$$= \underline{123.8}$$

A thin l.
former
temp 20°
steam to

Temp 0°C

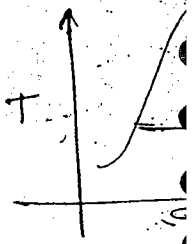
Sat pressure
kPa

neglect
the w
is say

(a) 10.3

$$\Rightarrow T_{\text{sat}} =$$

$$P_{\text{sat}} =$$



The fd

(1) cond
the

(2) cond
the

(3) cond
l

(4) cond
wr

(4) 2.3

basis
with on
stability ratio
be call
nd a
re
enthalpy of
4 in kw is

m_1
 m_2
 w_2
 p_2

$w_1 - w_2$

67

A thin layer of water in a field is formed after former has water at the ambient air condition are temp 20° and relative humidity 5% and extraction of steam table 0°C

Temp $^\circ\text{C}$	-15	-10	-5	0.01	5	10	-15	20
Sat pressure kpa	0.1	0.26	0.4	0.61	0.89	1.23	1.91	2.34

neglecting the heat transfer betw water and Ground the water temp in the field after full equilibrium is reached equals

- (a) 10.3 (b) -10.3 (c) -14.5 (d) 14.5

$$\Rightarrow T_{\text{sat}} = 20^\circ\text{C}$$

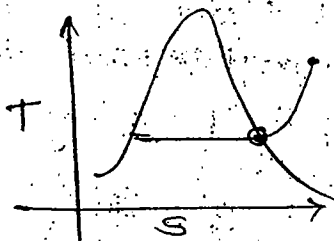
$$P_{\text{sat}} = 2.34$$

$$\phi = \frac{P_v}{P_{\text{sat}}} =$$

$$0.05 = \frac{P_v}{2.34}$$

$$P_v = 0.117 \text{ kpa}$$

Closer to 0.1



The following statement concern psychometric chart

- (1) constant ϕ lines are upslant straight lines to the right
- (2) constant WBT lines are down hill straight line to the right
- (3) constant specific volume lines are downhill straight line to the right
- (4) constant enthalpy lines are coincident with constant WBT lines

which statement are correct

- (a) 2,3 (b) 1,2 (c) 1,3 (d) 2,4

Air at DBT at 40°C and WBT at 20°C is dehumidified in air washer operating with continuous water recirculation the WBT at exists is 25% of that inlet. the DBT at the exit of air washer is closes to

- (a) 10°C (b) 20°C (c) 25°C (d) 30°C

$$\Rightarrow (\text{WBD})_{\text{entrance}} = 40 - 20 = 20^{\circ}\text{C}$$

$$\begin{aligned} (\text{wet bulb depression})_{\text{exist}} &= 0.25 (\text{WBD})_{\text{entrance}} \\ &= 0.25 \times 20 \\ &= \underline{5} \end{aligned}$$

$$(\text{DBT} - \text{WBT})_{\text{exist}} = 5$$

$$(\text{DBT} - 20) = 5$$

$$\underline{\text{DBT} = 25^{\circ}\text{C}}$$

A heat transformer is a device that transfers a part of heat supplied to it at intermediate temp to a high temp reservoir while rejecting the remaining part to a low temp heat sink. in such a transformer too if say heat is supplied at 350K the max amount of heat in kJ that can be transferred to 400K when the rest is rejected to heat sink at 300K is

- (a) 12.5 (b) 14.29 (c) 33.33 (d) 57.14

$$\Rightarrow \oint \frac{dQ}{T} = \frac{100}{350} - \frac{Q}{400} - \frac{(100-Q)}{300} = 0$$

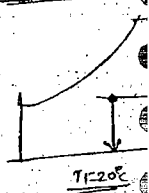
$$100 \rightarrow \begin{array}{c} \boxed{400\text{K}} \\ \text{Heat Engine} \\ \boxed{350\text{K}} \\ \text{Heat Engine} \\ \boxed{300\text{K}} \end{array} = 100 + \frac{Q}{3} = 57.14$$

$$W_{15} = \left(\frac{350}{25} \right)^n$$

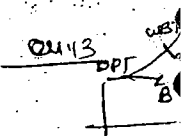
$$(C \cdot O P)_n$$

$$\frac{Q}{W F}$$

Psychrom



$$\frac{Q_{110}}{N} = \frac{Q}{W_{15}}$$



$$Q_{114}$$

$$Q_{115}$$

humidified
per
hot inlet
to a

$$W_E = \left(\frac{350 - 300}{250} \right) (100 - Q)$$

$$(C.O.P)_{H.P} = \left(\frac{400}{400 - 350} \right) = \frac{Q + W_E}{W_E} = 1 + \frac{Q}{W_E}$$

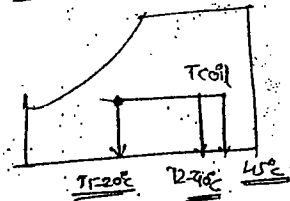
$$\frac{Q}{W_E} =$$

$$Q = 2W_E$$

$$= 2 \left[\frac{100 - Q}{2} \right]$$

$$Q = 50$$

Psychrometer



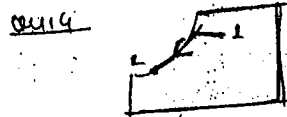
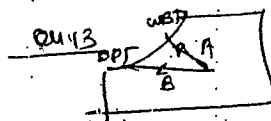
$$BPF = \frac{T_{coil} - T_2}{T_{coil} - T_1}$$

$$= \frac{45 - 40}{45 - 20}$$

$$\frac{Q_{H2O}}{M} = \frac{W}{W_5} = \frac{0.623 \cdot \frac{P_V}{P_{sat} - P_V}}{0.623 \cdot \frac{P_{sat}}{P_{atm} - P_{sat}}}$$

$$= \frac{P_V}{P_{sat}} \times \left(\frac{P_{atm} - P_{sat}}{P_{atm} - P_V} \right)$$

$$= \phi \times \left(\frac{P_{atm} - P_{sat}}{P_{atm} - P_V} \right)$$



$$\text{SHF} = \frac{SHL}{SHL + LHL}$$

$$= \frac{SHL}{SHL + 0.75 SHL}$$

$$= 0.8$$

spers
te temp
remaining

350K

transferred
link of

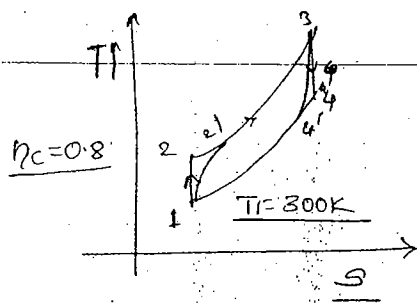
$$= 80 + \frac{80}{2}$$

$$= 57.14$$

Gas turbine : Low pressure

conventional

Ques 1



$$T_3 = 875 + 273 = 1148K$$

$$\eta_T = 0.85$$

$$r_p = 4$$

$$C_p = 42000 \text{ kJ/kg}$$

$$T_2' = T_1 + \frac{(T_3 - T_1)}{\eta_c}$$

$$T_2 = T_1 (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$= 300 (4)^{\frac{0.4}{1.4}}$$

$$= 446K$$

$$T_2' = T_1 + \frac{T_2 - T_1}{\eta_c} = 300 + \frac{446 - 300}{0.8}$$

$$= 483K$$

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

$$T_4 = \frac{T_3}{(r_p)^{\frac{1-\gamma}{\gamma}}} = \frac{1148}{(4)^{\frac{0.4}{1.4}}} = 772.5K = 773K$$

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

$$T_4' = T_3 - \eta_T (T_3 - T_4)$$

$$= 1148 - 0.85 (1148 - 773)$$

$$= 829.25K$$

$$W_T = C_p (T_3 - T_4')$$

$$= 1 (1148 - 820)$$

$$= 318 \text{ kJ/kg}$$

$$W_C = C_p (T_2' - T_1)$$

$$= 1 (483 - 300)$$

$$= 183 \text{ kJ/kg}$$

US =

Qe =

kinet =

work

back work

$\eta_{th} =$

Air ra

Heat

Mean

Mean

$$Q_s = c_p (T_3 - T_2')$$

$$= 1 (1148 - 483)$$

$$= 665 \text{ kJ}$$

$$Q_R = c_p (T_4' - T_1)$$

$$= 1 (830 - 300)$$

$$= 530 \text{ kJ}$$

$$W_{\text{net}} = W_T - W_C$$

$$= 318 - 183$$

$$= 135$$

$$\text{work ratio} = \frac{W_{\text{net}}}{W_T} = \frac{135}{318} = 0.42$$

$$\text{back work ratio} = \frac{W_C}{W_T} = \frac{183}{318} = 0.57$$

$$\eta_{\text{th}} = \frac{Q_s - Q_R}{Q_s} = \frac{665 - 530}{665} = 0.2$$

$$\text{Air rate} = \frac{3600}{W_T - W_C} = \frac{3600}{215}$$

$$\text{Heat rate} = \frac{3600}{0.2} = 18000 \text{ kJ/kWh}$$

$$T = 223 \text{ K}$$

$$\text{Mean temp of heat supplied} = T_{m1} = \frac{c_p (T_3 - T_2')}{c_p \ln(T_3/T_2')}$$

$$= \frac{T_3 - T_2'}{\ln(T_3/T_2')}$$

$$= \frac{1148 - 483}{\ln \frac{1148}{483}}$$

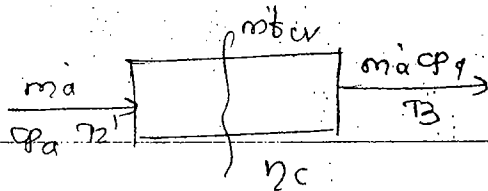
$$= 768.1$$

$$\text{Mean temp of heat rejection } T_{m2} = \frac{c_p (T_4' - T_1)}{c_p \ln(T_4'/T_1)}$$

$$= \frac{830 - 300}{\ln \frac{830}{300}}$$

$$= 520.8$$

Air fuel ratio =



Apply the energy balance eqn.

$$\dot{m}_a \cdot c_{p_a} \cdot T_2' + \dot{m}_f (cv) \eta_c = \dot{m}_a c_{p_a} T_3$$

divide by $\dot{m}_f$

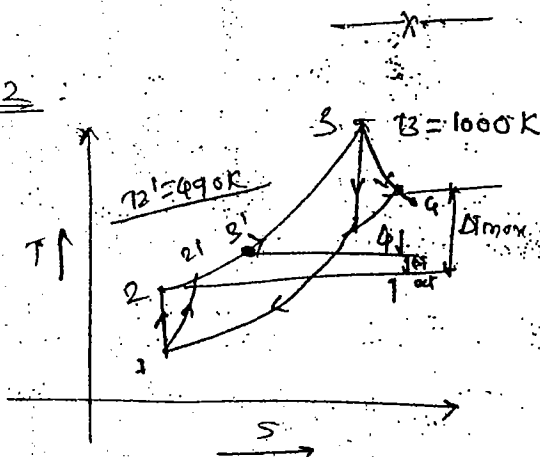
$$\frac{\dot{m}_a}{\dot{m}_f} c_{p_a} T_2' + (cv) \eta_c = \frac{\dot{m}_a}{\dot{m}_f} c_{p_a} T_3$$

$$(AFR) c_{p_a} T_2' + (cv) \eta_c = (AFR) c_{p_{air}} T_3$$

$$(AFR) (1) 483 + (42000) 0.9 = 1 \times 1148 (AFR) 1 \times 1148$$

$$\boxed{AFR = 56.84}$$

Q4.2



$$\eta_T = 0.8$$

$$r_p = 5$$

$$\text{efficiency } \epsilon = 0.8$$

process 1-2:

$$\begin{aligned} T_2 &= T_1 (r_p)^{\frac{\gamma-1}{\gamma}} \\ &= 300 (5)^{\frac{0.4}{1.4}} \\ &= 475.14 \end{aligned}$$

$$T_2' > T_2$$

η_T

$$T_4 = \frac{T_3}{(r_p)^{\frac{\gamma-1}{\gamma}}} = \frac{1000}{5^{\frac{0.4}{1.4}}} = \underline{632 \text{ K}}$$

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

$$\begin{aligned} T_4' &= T_3 - \eta_T (T_3 - T_4) \\ &= 1000 - 0.8(1000 - 632) \\ &= \underline{705 \text{ K}} \end{aligned}$$

$$\begin{aligned} \text{efficiency } e &= \frac{(\Delta T)_{\text{act}}}{(\Delta T)_{\text{max}}} \\ &= \frac{T_3' - T_2'}{T_4' - T_2'} \end{aligned}$$

$$0.8 = \frac{T_3' - 490}{705 - 490}$$

(AFR) 1x1148

$$\boxed{T_3' = 662 \text{ K}}$$

$$W_T = C_p \Delta T_3$$

~~W~~

$$Q_S = C_p (T_3 - T_3')$$

$$= \underline{338 \text{ W}}$$

$$Q_R = C_p (T_4' - T_1)$$

0.8

$$W_T = C_p (T_3 - T_4')$$

$$= \underline{295 \text{ W}}$$

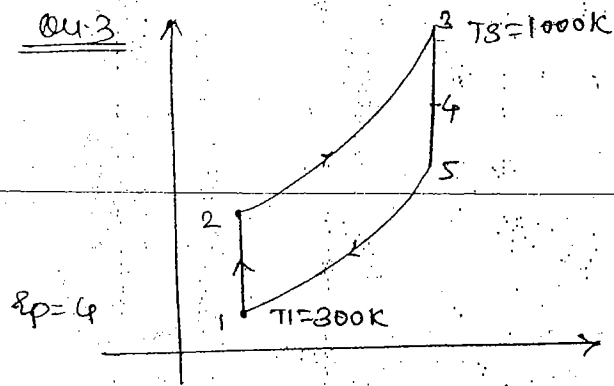
$$W_C = C_p (T_2' - T_1)$$

$$= 1(490 - 300)$$

$$= \underline{190 \text{ W}}$$

$$\eta_T = \frac{W_{\text{net}}}{Q_S} = \frac{295 - 190}{338} = \underline{0.31}$$

Qu. 3



$$T_2 = T_1 (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$= 300(4)^{\frac{0.4}{1.4}}$$

$$= 446 \text{ K}$$

$$K_{LC} = K_T$$

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

$$446 - 300 = (1000 - T_4)$$

$$146 = 1000 - T_4$$

$$T_4 = 854 \text{ K}$$

$$\frac{T_3}{T_4} = (r_p)^{\frac{\gamma-1}{\gamma}}_{\text{HPT}}$$

$$\frac{1000}{854} = (r_p)^{\frac{0.4}{1.4}}$$

$$1.17 = (r_p)^{0.2857}_{\text{HPT}}$$

$$(r_p) = 1.73$$

$$(r_{pC}) = (r_p)_{\text{LPT}} \times (r_p)_{\text{HPT}}$$

$$4 = (r_p)_{\text{LPT}} \times 1.73$$

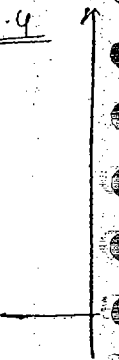
$$(r_p)_{\text{LPT}} = 2.32$$

$$\frac{T_4}{T_5}$$

$$\frac{854}{T_5}$$

Kgen

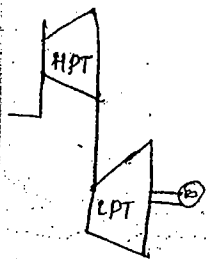
Qu. 4



pow

$$\frac{m a c_p}{C_p a T_2}$$

At



$$\frac{T_4}{T_5} = (r_p)_{LPT}$$

$$\frac{854}{T_5} = \underline{2.32}$$

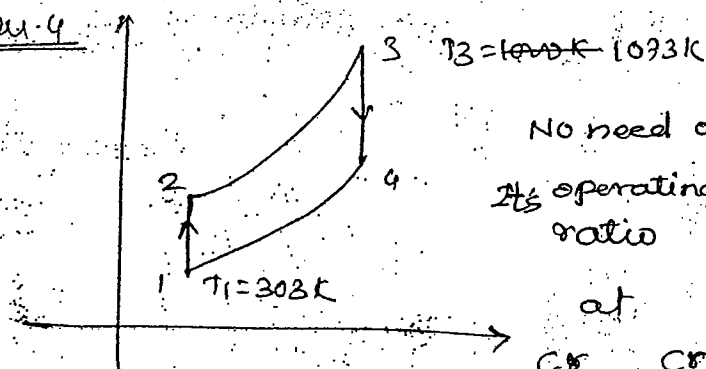
$$\boxed{T_5 = 673K}$$

$$K_{generator} = c_p (T_4 - T_5)$$

$$= 1(854 - 673)$$

$$= \underline{181 \text{ kJ/kg}}$$

Ques 4



No need of regenerator means
It's operating at critical pressure
ratio

at

critical pressure ratio

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

$$= \sqrt{303 \times 1073}$$

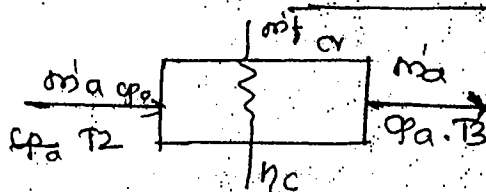
$$W_{net} = c_p (\sqrt{T_3} - \sqrt{T_1})^2$$

$$= 1 (\sqrt{1073} - \sqrt{303})^2$$

$$= 235.6 \text{ kJ/kg}$$

$$\text{power} = 100 \text{ kW} = \dot{m}_a (c_p) \dot{m}_a \text{ (kg/sec)} \quad W_{net} (\text{kJ/kg})$$

$$\dot{m}_a = 0.424 \text{ kg/sec}$$



Apply energy balance

$$\dot{m}_a c_p a \cdot T_2 + (\dot{m}_f) c_v \eta_c = \dot{m}_a c_p a T_3$$

divide by $\dot{m}_f$

$$\frac{\dot{m}_a}{\dot{m}_f} c_p a T_2 + (c_v) \eta_c = \frac{\dot{m}_a}{\dot{m}_f} c_p a T_3$$

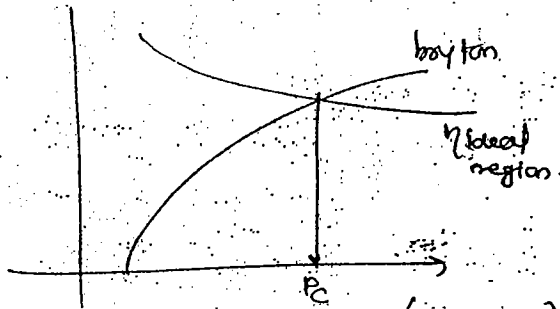
$$(AFR) \times 1 \times 570.2 + 4500 \times 1 = (AFR) (1) \times 1073$$

$$(AFR) 570.2 + 4500 = (AFR) 1073$$

$$AFR = 89.49 = \frac{\dot{m}_a}{\dot{m}_f} = \frac{0.424}{\dot{m}_f}$$

$$\dot{m}_f = 4.23 \times 10^{-3}$$

* The min & max temp in cycle are 800K & 1200K respectively. It is operating at 60% of critical pressure ratio then what is the efficiency of a simple brayton cycle and also an ideal regenerative cycle and what is the gain in efficiency due to ideal regeneration.



$$(\gamma_{pc}) = \left(\frac{T_{max}}{T_{min}} \right)^{\frac{\gamma}{2(\gamma-1)}}$$

$$= \left(\frac{1200}{800} \right)^{\frac{1.4}{2 \times 0.4}} = 11.31$$

$$(\gamma_p)_{actual} = 0.6 (\gamma_p)_c$$

$$= 0.6 \times 11.32$$

$$= 6.79$$

$$\eta_{brayton} = 1 - \left(\frac{1}{\gamma_p} \right)^{\frac{\gamma-1}{\gamma}}$$

$$= 1 - \left(\frac{1}{6.79} \right)^{\frac{0.4}{1.4}}$$

$$= 0.42$$

78

424
of

or & 1200 K
initial
ry of
regenerative
ry due to

$$(\eta)_{\text{ideal}} = 1 - \frac{T_{\min}}{T_{\max}} \left(\gamma \right)^{\frac{r-1}{r}}$$

$$= 1 - \frac{300}{1200} (6.79)^{\frac{0.4}{1.4}}$$

$$= 0.567$$

$$\eta = \frac{0.567 - 0.42}{0.567}$$

$$= \underline{\underline{0.2635\%}}$$

Ques 9 if there were many of expansion & heating area to have temp sensible adiabatic expansion become isothermal expansion, and sensible adiabatic compression become isothermal compression, and brayton cycle become Ericsson cycle

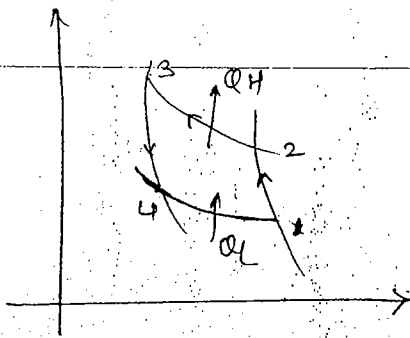
Ans In regenerative cycle

$$Q_T \rightarrow W_C \rightarrow W_{\text{net}} \rightarrow$$

Not dependent on Q_S

Refrigeration

Ideal refrigerator function on reversed Carnot cycle



1-2 $\Rightarrow$ Reversible Adiabatic compression

2-3 $\Rightarrow$ Isothermal heat rejection

3-4 $\Rightarrow$ Reversible Adiabatic expansion

4-1 $\Rightarrow$ Isothermal heat absorption

$$(C.O.P) = \frac{T_L}{T_H - T_L} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$T_1 V_1^{r-1} = T_H V_2^{r-1}$$

$$\frac{T_H}{T_L} = \left(\frac{V_1}{V_2} \right)^{r-1} = \epsilon_k^{r-1}$$

$$\epsilon_k = \text{compression ratio} = \frac{V_1}{V_2}$$

$$\epsilon_p = \text{pressure ratio} = \frac{P_2}{P_1}$$

$$T_L \cdot P_1^{\frac{1-r}{r}} = T_H \cdot P_2^{\frac{1-r}{r}}$$

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

$$C.O.P = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{1}{\epsilon_k^{\frac{r-1}{r}} - 1} = \frac{1}{\epsilon_p^{\frac{r-1}{r}} - 1}$$

1 ton of refrigeration:

1 ton of refrigeration defined as amount of heat removed from 200 pounds of H_2O at $32^\circ F$ to converted into ice at $32^\circ F$ in 24 hrs.

1 ton

SI defi

from 1000
in 24 hrs

1 ton of

Refrigeration cycle

1. compression

2. rejection

3. expansion

4. absorption

$$1 \text{ ton of refrigeration} = \frac{\text{mass of ice} \times \text{latent heat of ice}}{\text{time}}$$

$$= \frac{2000 (\text{lbs}) \times 144 \frac{\text{Btu}}{\text{lb}}}{24 \text{ hr}}$$

$$= 12000 \frac{\text{Btu}}{\text{hr}}$$

$$= 3000 \text{ kcal/hr} \rightarrow \text{MKW}$$

$$= 50 \text{ kcal/min}$$

$$= 211 \text{ kJ/min}$$

$$= \underline{\underline{3.517 \text{ kW}}}$$

SI definition:

It is defined as the amount of heat removed from 1000 kg of water at 0°C to convert into ice at 0°C in 24 hrs.

$$1 \text{ ton of ref} = \frac{\text{mass of ice} \times \text{Latent heat of ice}}{\text{time}}$$

$$= \frac{1000 \text{ kg} \times 336 \text{ kJ/kg}}{24 (\text{hrs})}$$

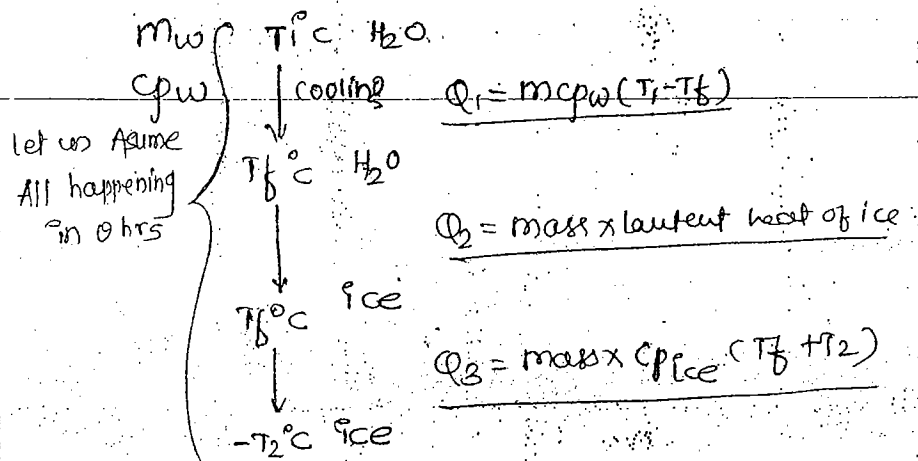
$$= 14000 \text{ kJ/hr}$$

$$= 233.33 \text{ kJ/min}$$

$$= \underline{\underline{388 \text{ kW}}} \quad (\text{we are not using})$$

f head
to

cooling load calculation



cooling load in (kw) :

$$(C.L.) = \frac{Q_1 + Q_2 + Q_3}{3600 \text{ }^\circ}$$

$$= \frac{m}{3600 \text{ }^\circ} [c_{pw} (T_1 - T_f) + L_{ice} + c_{pice} (T_f + T_2)]$$

For water $T_f = 0$

$$C.L. (kw) = \frac{m}{3600 \text{ }^\circ} [c_{pw} T_1 + L_{ice} + c_{pice} T_2]$$

$$C.L. (\text{tons of refrigeration}) = \frac{C.L. (kw)}{3.517}$$

* 1000 kg of water at 40°C is to be cooled to water at -20°C in 6 hrs. the freezing temp of H_2O is 0°C what is cooling load in terms of refrigeration

$$\Rightarrow m = 1000 \text{ kg} \quad t = 40^\circ \text{C} \quad T_2 = -20$$

C.L (kw)

cooling

* 5000 kg

- 30°C

- 5°C @

latent heat

solid fr

$\Rightarrow m = 5$

C.L

C.L

$$\begin{aligned}
 C.L (kW) &= \frac{m}{3600 \theta} [c_{pw} T_1 + L + c_{pi} T_2] \\
 &= \frac{1000}{3600 \times 6} [4.2 \times 40 + 336 + 2.1 \times 20] \\
 &= \underline{25.25 \text{ kW}}
 \end{aligned}$$

$$\text{Cooling load (TR)} = \frac{25.25}{3.517} = \underline{7.18}$$

* 5000 kg of fish at 25°C is to be cooled to fish at -30°C in 24 hrs the freezing temp of fish is -5°C . Specific heat of liquid fish is 2 kJ/kgK , latent heat of fish is 200 kJ/kg and specific heat of solid fish is 1 kJ/kgK . What is the cooling load in TR?

$$[T_f + T_2]$$

$$\Rightarrow m = 5000$$

$$C.L (kW) = \frac{Q_1 + Q_2 + Q_3}{3600}$$

$$= \frac{m}{3600 \theta} [c_{pw} (T_1 - T_f) + L + c_{ice} (T_f + T_2)]$$

$$= \frac{5000}{3600 \times 24} [2 (25 - (-5)) + 200 + 1 (-5 - (-30))]$$

$$= 16.5 \text{ kW}$$

$$C.L (TR) = \frac{16.5}{3.517} = 4.68$$

Cooled
freezing
in terms

Relative c.o.p & relative efficiency:-

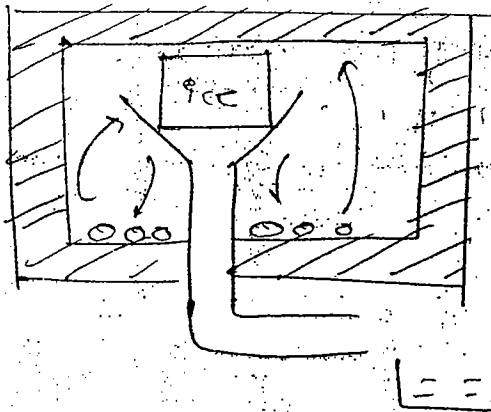
$$\frac{(\text{Relative})_{\text{c.o.p}}}{\text{or}} = \frac{(\text{c.o.p})_{\text{act}}}{(\text{c.o.p})_{\text{theoretical}}}$$

$$(\text{Relative})_{\eta} = \frac{(\text{c.o.p})_{\text{act}}}{(\text{c.o.p})_{\text{theoretical}}}$$

$$(\text{c.o.p})_{\text{theor}} = (\text{c.o.p})_{\text{Carnot}}$$

Methods of refrigeration:

Ice refrigeration:



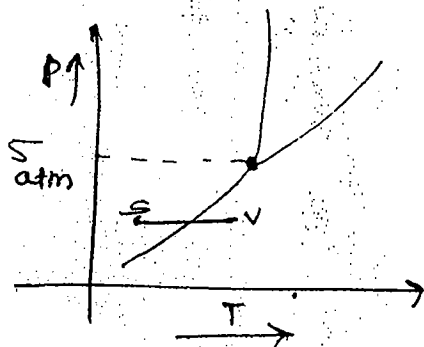
Convection principle used

used for temp $> 0^{\circ}\text{C}$

Dry Ice refrigeration

Dry Ice is solid carbon dioxide.

Solid carbon dioxide has a triple point pressure of 5 atm



if any substance is heated

if it is kept 1 atm pressure it absorbs the heat from surroundings get converted from solid to vapor and process is called sublimation

This method is used for storage of fruits, vegetable in transit

Evapor

Evapor the pri transfer

evapor velocity

Area e. product

principle cooling refng

Air re

1. Air from air ref

The lo which

principle

Evaporative refrigeration

Evaporation produces a cooling effect and this is the principle of refrigeration. It is an adiabatic transfer of heat from air to water.

Evaporation rate depends upon area and velocity. Velocity of air is high, the evaporation is high. Area exposed is high, evaporation is high. Evaporation produces a cooling effect.

Principle uses is Adiabatic evaporation of heat cooling of water & ponds are examples of evaporative refrigeration.

Air refrigeration

1. Air refrigeration of air. Adiabatic expansion of air from high pressure to lower pressure is called as air refrigeration.

$$T_2 = T_1 \cdot r_p^{\frac{\gamma-1}{\gamma}}$$

$$P_1 = 5 \text{ bar}$$

$$T_1 = 300 \text{ K}$$

$$P_2 = 1 \text{ bar}$$

$$T_2 = ?$$

$$T_2 = 300 \left(\frac{1}{5} \right)^{\frac{0.4}{1.4}}$$

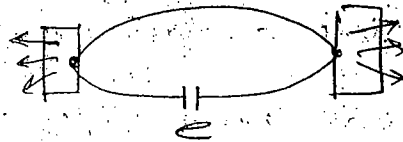
$$= \underline{189 \text{ K}} \approx \underline{-84^\circ \text{C}}$$

The low temp of air circulated around the space which is to be refrigerated.

Principle Adiabatic expansion of air from high pressure to low pressure.

Thermoelectric refrigeration

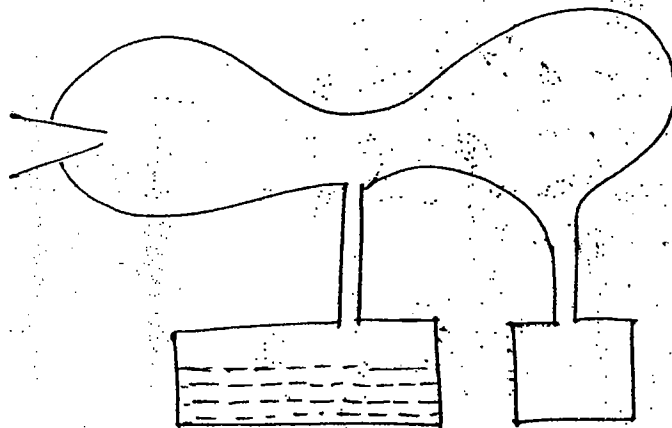
It based on principle of peltier effect
peltier effect is opposite of seebeck effect.



A thermocouple emf is given then heat is absorbed in one junction and heat is liberated at the other junction and the principle is called peltier effect.

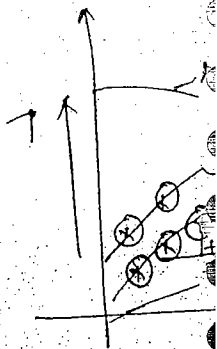
This is light in weight highly reliable but efficiency is very less. It is basically used in air craft for refrigeration purpose.

Steam jet refrigeration:



low pressure steam is required for this purpose when low pressure steam is expanded through a nozzle at the throat very low pressure is produced. which will reduce the pressure from the surface of water to about 6.5 cm of H_2O and water boils at low temp of $6.5^\circ C$ or at water evaporates it produces a boiling effect in the remaining water.

Total



The slope of the temp is given by the temp

The line is called a

temp of and the

$M(\text{ve})$

dp is -ve

dT is -ve

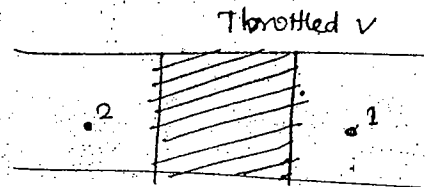
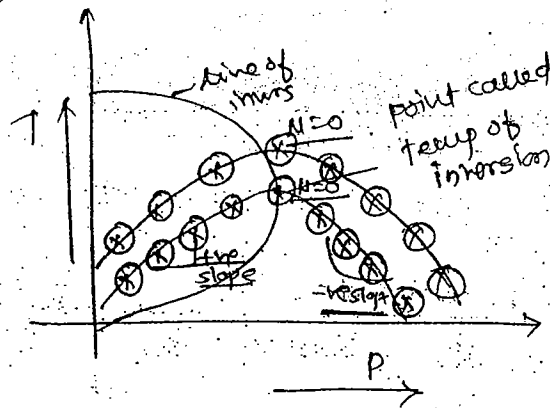
$T_f - T_i < 0$

$T_f < T_i$

cooling effect

Joule Thomson coefficient or throttling process

$$\left(\mu = \frac{\partial T}{\partial P} \right)_{h=c}$$



The slo point of where slope of curve is zero is called as the temp of inversion i.e. the point where the curve changes its slope. Temp behaviour of fluid due to throttling process is given by the Joule Thomson coefficient. The locus of all the temp of inversions is called as line of inversion.

The line of inversion meet $P=0$ at T_{max} which is called as the max temp of inversion.

Every substance will have its own maximum temp of inversion below the maximum temp of inversion and the sloped region only the refrigeration is produced.

$\mu(+ve)$

dp is $+ve$

dT is $-ve$

$T_f - T_i < 0$

$T_f < T_i$

cooling effect

$\mu(-ve)$

dp is $(+ve)$

dT is $(+ve)$

$T_f - T_i > 0$

$T_f > T_i$

Heating effect

described
or function

y reliable
condition

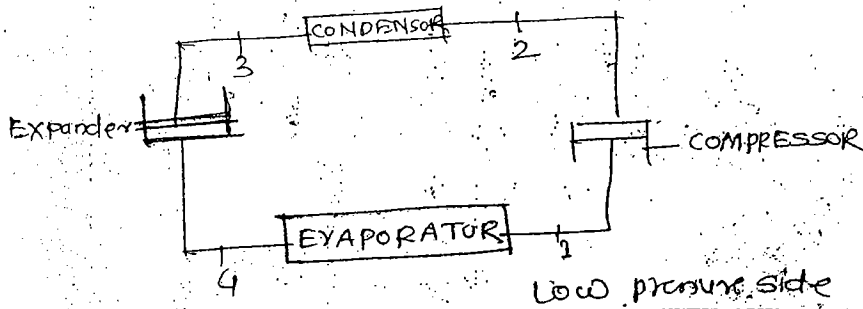
purpose

at the
it will
outlet to
a temp
duals a

Bell Coleman cycle / Reversed Joule cycle

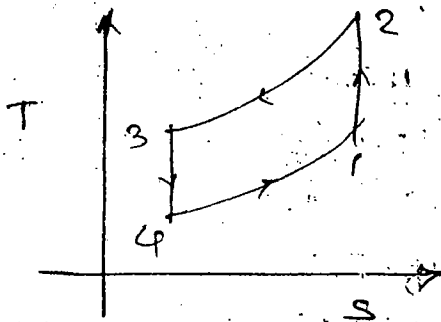
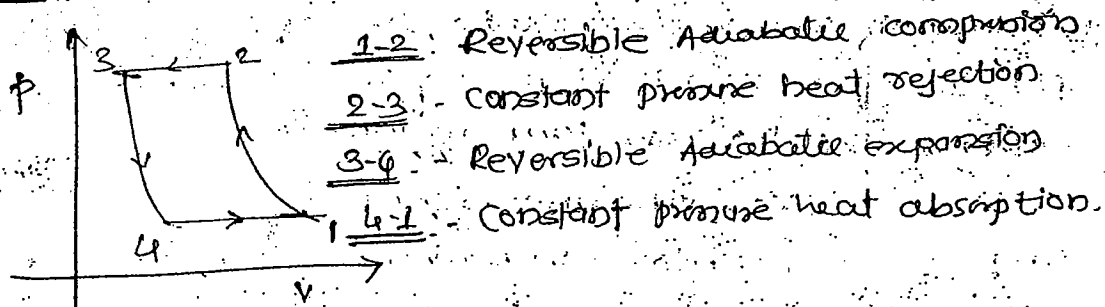
Reversed bryton cycle

High pressure side



The compressor connect the low pressure side to high pressure side. and expander connects a high pressure side to low pressure side

reversed Joule cycle / Bryton cycle



$$r_p = \text{pressure ratio} = \frac{P_3}{P_4} = \frac{P_2}{P_1}$$

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

$\epsilon_k = \text{con}$

Net work

Heat

$W =$

$= C$

C.O.P.

General

polymer

(C.O.)

If

C.O.

C.O.

This is
refrigerator
it is

ycle/

ycle

c to
is a high

compression
rejection
expansion
absorption.

$$= \frac{P_2}{P_1}$$
$$= \left(\frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\epsilon_k = \text{compression ratio} = \frac{V_1}{V_2}$$

$$\text{Net refrigerating effect}_{(NRE)} = C_p(T_1 - T_4)$$

$$\text{Heat rejected } Q_R = C_p(T_2 - T_3)$$

$$W = Q_R - NRE$$
$$= C_p(T_2 - T_3) - C_p(T_1 - T_4)$$

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

$$= \frac{1}{\left[\frac{T_2 - T_3}{T_1 - T_4} \right] - 1}$$

General expression of c.o.p of a system Assuming
polytropic expansion & polytropic compression is given by

$$(C.O.P) = \frac{T_1}{\left(\frac{\gamma}{\gamma-1} \right) \left(\frac{\gamma-1}{\gamma} \right) (T_2 - T_1)}$$
$$= \frac{T_4}{\left(\frac{\gamma}{\gamma-1} \right) \left(\frac{\gamma-1}{\gamma} \right) (T_3 - T_4)}$$

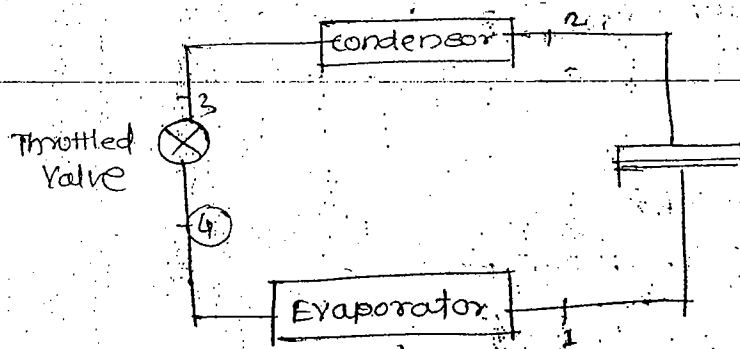
$$\text{If } \gamma = \gamma$$

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

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

This system is light in weight uses a cheap
refrigerant i.e. air and it is non toxic ... why
it is used in air craft engine.

Vapor compression refrigeration system (VCR)



SFEE

$$h_1 + Q = h_2 + W$$

1-4 Evaporator

No work done only heat absorption

Apply SFEE

$$h_4 + Q_E = h_1 + 0$$

$$Q_E = h_1 - h_4 \text{ kJ/kg}$$

Q_E called as Net refrigerating effect

1-2 Compressor

$$Q = 0 \quad S = C$$

Apply SFEE

$$h_1 + 0 = h_2 + W_C$$

$$W_C = h_2 - h_1 \text{ kJ/kg}$$

Am -ve indicating that work is being done on the system

$$h_2 + Q$$

The answer
the sys.

3-4

$$h_3 + 0$$

here

flash

hence

net

C.O.P

VCR)

2-3 condensor

No work is done $W=0$

$$h_2 + Q_c = h_3 + 0$$

$$\boxed{Q_c = h_3 - h_2 \text{ kJ/kg}} \text{ or } h_2 - h_3 \text{ kJ/kg}$$

The answer is $-ve$ indicating that heat is rejected by the system.

3-4 throttle valve

$$\underline{W=0} \quad \underline{Q=0}$$

$$h_3 + 0 = h_4 + 0$$

$$\boxed{h_3 = h_4}$$

here state 3 saturated liquid state where as state 4 liquid + vapor state

$$h_3 = h_4 \\ = h_{f4} + x(h_{g4} - h_{f4})$$

$$\boxed{x = \frac{h_3 - h_{f4}}{h_{g4} - h_{f4}}}$$

x is called dryness fraction flash gas

RE = refrigerating effect

flash gas does not contribute to refrigerating effect hence the value of x is less it indicate high net RE

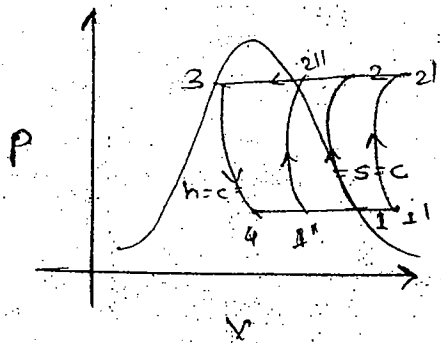
$$C.O.P = \frac{NRE}{\text{Work}} = \frac{h_1 - h_4}{h_2 - h_1}$$

kJ/kg

net on the

the compressor connect low pressure side to high pressure side and throttle valve connect high pressure side to the low pressure side

VCR on various plane

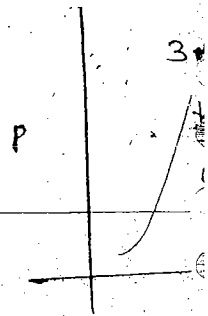
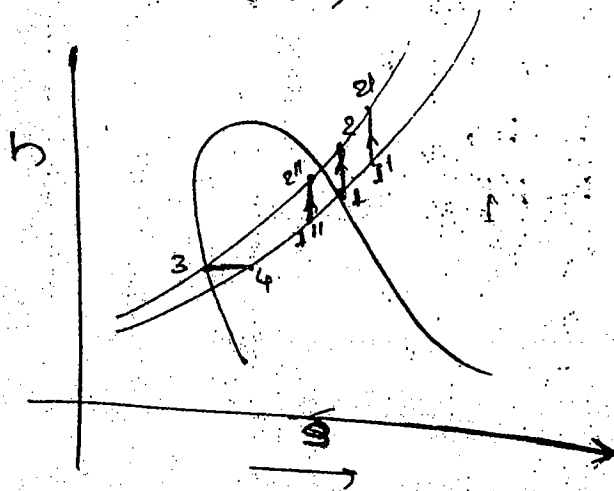
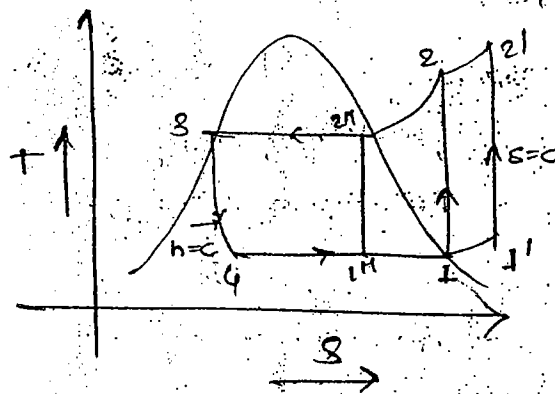


The compression starts on the dry and saturated vapor line. it is called as standard vapor compression cycle and after condensation the refrigerant is in saturated liquid state

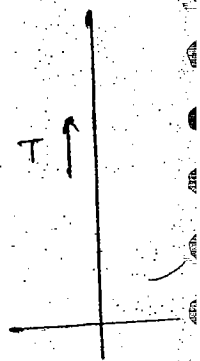
1-2-3-4 :- standard V.C.R. cycle

1'-2'-3'-4' :- superheated V.C.R. cycle

1''-2''-3''-4'' :- wet V.C.R. cycle



Design



NR

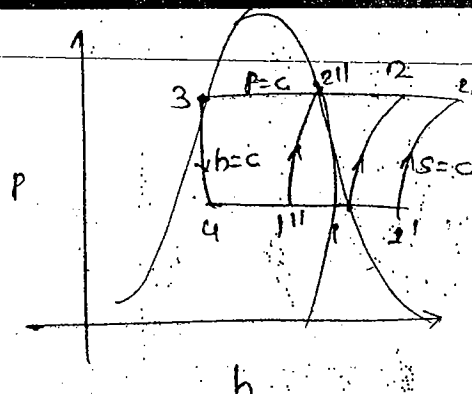
NEE

m_g

m_g

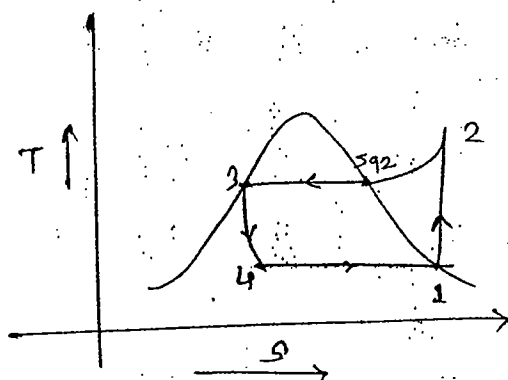
here

gth
pressure



in the
or line
load
and
re
mixed

Design of VC system for α tons of refrigeration



$$NRE = (h_1 - h_4) \text{ kJ/kg}$$

$$NRE \text{ (kW)} = 8.517 \alpha$$

$$\dot{m}_g \left(\frac{\text{kg}}{\text{sec}} \right) (h_1 - h_4) \text{ (kJ/kg)} = NRE \text{ (kW)}$$

$$\dot{m}_g \left(\frac{\text{kg}}{\text{sec}} \right) = \frac{8.517 \alpha}{h_1 - h_4}$$

here 1-2 $S_1 = S_2$ $S_2 > S_{g2}$ $\therefore$ after compression it is superheated state

$$S_2 = S_{g2} + c_{pv} \ln \frac{T_2}{T_{\text{sat}}}$$

$$\ln \frac{T_2}{T_{\text{sat}}} = \frac{S_2 - S_{g2}}{c_{pv}}$$

$$T_2 = T_{\text{sat}} e^{\left(\frac{S_2 - S_{g2}}{c_{pv}} \right)}$$

Volume

and

7 vol

1



cond
com

$$S_1 = 1$$

21

$$S_1 =$$

5.

•

•

•

$$\text{Volume flow rate } \dot{V} (\text{m}^3/\text{sec}) = \dot{m}_s (\text{kg/sec}) v_1 (\text{m}^3/\text{kg})$$

$$= \underbrace{\frac{\pi D^2 L n}{4} \times \frac{N}{60}}_{\text{theoretical stroke vol}} \times \eta_{\text{vol}}$$

theoretical
stroke vol

TSR flow rate (m^3/sec)

Actual SVFR (m^3/sec)

$$\eta_{\text{vol}} = 1 + C - C \left(\frac{p_2}{p_1} \right)^{1/n}$$

$C \rightarrow$ clearance ratio

$\frac{p_2}{p_1} \rightarrow$ pressure ratio

$n \rightarrow$ polytropic index

Wet compression

condition of refrigerant before
compression is given

$$s_1 = s_{f1} + x_1 (s_{g1} - s_{f1})$$

$$h_1 = h_{f1} + x_1 (h_{g1} - h_{f1})$$

at

$$s_1 = s_2 \quad s_2 < s_{g2} \text{ (wet state)}$$

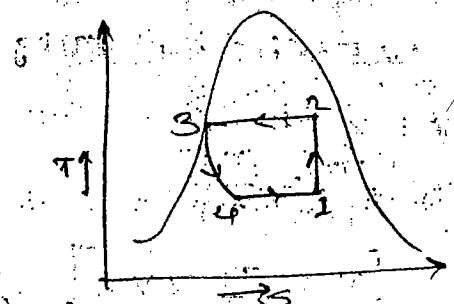
g/kg

$$s_2 = s_{f2} + x_2 (s_{g2} - s_{f2})$$

$$x_2 = \frac{s_2 - s_{f2}}{s_{g2} - s_{f2}}$$

$$h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

$$v_1 = v_{f1} + x_1 (v_{g1} - v_{f1})$$

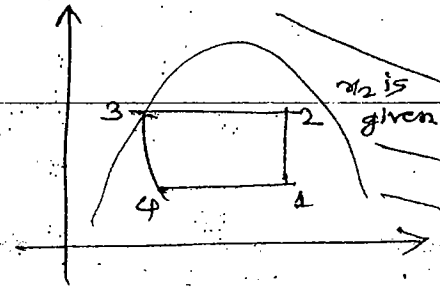


condition of refrigerant after compression x_2 is given

$$s_2 = s_{f2} + x_2 (s_{g2} - s_{f2})$$

$$h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

$$s_2 = s_1 \quad s_1 > s_{g1} \text{ wet state}$$



at condition given

$$s_2 = s_1$$

$$h_2 = h_1$$

$$s_2 = s_1$$

$$s_1 = s_1$$

$$x_2$$

$$h_1 =$$

$$v_1 =$$

when problem with

effect of a

NRE C

NRE C

m r c

v, (h

volume

press

rat

c.o

Compon

Superheated compression

if superheating is done inside evaporator

$$NRE = (h_1 - h_4) \text{ kJ/kg}$$

if superheating is outside the evaporator is

$$NRE = (h_5 - h_4) \text{ kJ/kg}$$

$$NRE = ch$$

$$\frac{v_1}{T_1} = \frac{v_5}{T_5}$$

$$v_1 = \frac{T_1}{T_5} \times v_5 \quad \text{specific vol at suction}$$

$$s_1 = s_5 + c_{pv} \ln \frac{T_1}{T_5}$$

$$\ln \frac{T_1}{T_5} = \frac{s_1 - s_5}{c_{pv}}$$

$$\frac{T_1}{T_5} = e^{\left(\frac{s_1 - s_5}{c_{pv}} \right)}$$

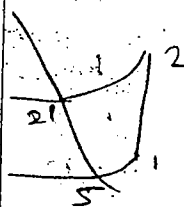
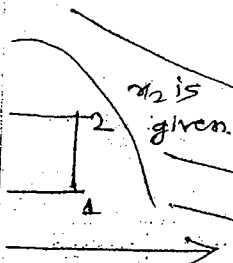
$$T_1 = T_5 e^{\left(\frac{s_1 - s_5}{c_{pv}} \right)}$$

$$s_1 = s_2 + s_2' + c_{pv} \ln \frac{T_2}{T_2'}$$

$$\ln \frac{T_2}{T_2'} = \frac{s_1 - s_2'}{c_{pv}}$$

$$T_2 = T_2' \left\{ e^{\frac{s_1 - s_2'}{c_{pv}}} \right\}$$

x_2 is given



Vapor
in cycle

$$h_2 = h_2' + c_p v (T_2 - T_2')$$

aff

Condition for refrigerant after compression x_2 is

given

$$s_2 = s_{f2} + x_2 (s_{g2} - s_{f2})$$

$$h_2 = h_{f2} + x_2 (h_{g2} - h_{f2})$$

$$s_2 = s_1 \quad s_1 > s_g \text{ wet state}$$

$$s_1 = s_{f1} + x_2 (s_{g1} - s_{f1})$$

$$x_1 = \frac{s_1 - s_{f1}}{s_{g1} - s_{f1}}$$

$$h_1 = h_{f1} + x_1 (h_{g1} - h_{f1})$$

$$v_1 = v_{f1} + x_1 (v_{g1} - v_{f1})$$

When nothing is mentioned about the condition of problem we assume std VCR and processed with problems.

effect of operating variable on the performance of a VCR cycle

NRE (kW) is constant

NRE (kJ/kg) decreases

$\dot{m}_r$ (kg/sec) increases

v_1 (m³/kg) is constant

Volume flow rate (m³/sec) ↑

pressure ratio ↑

$\eta_{\text{volumetric}}$ ↓

W_C ↑
(kJ/kg)

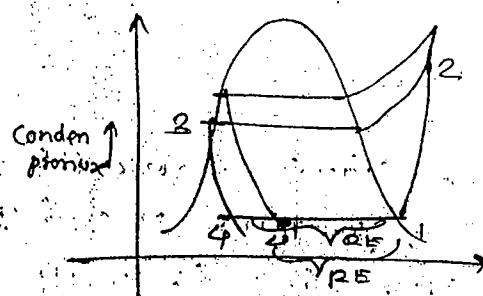
W (kW) ↑

C.O.P ↓

condenser load (kW) ↑

$\dot{m}_{wC}$ (kg/sec) ↑

Compressor discharge increases.



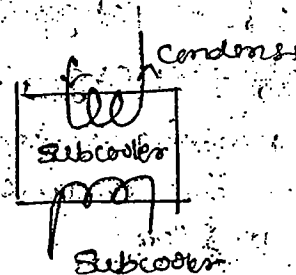
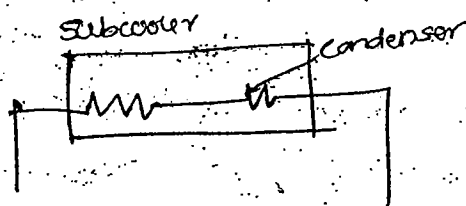
Continued on page no (4)

$NRE (KJ/kg) \uparrow$ $m \dot{r} (kg/kg) \downarrow$ $v_1 (m^3/kg) \rightarrow$ HP no 3
 Volume flow rate $(m^3/kg) \downarrow$ $\eta_{vol} \rightarrow$
 cylindrical dimension $\downarrow$ $W_{ck} (kg) \rightarrow$ $c.o.p \uparrow$ $W_{ck} (kw) \downarrow$
 Condenser load $(kw) \downarrow$ $m \dot{w} (kg/sec)$ compressor
 discharge temp $\rightarrow$ flash gas $\downarrow$

when dry saturated vapor is send into the cylinder
 it comes in contact with the cold cylindrical wall
 and suffer condensation the liquid refrigerant washes
 a cylinder lubricating oil and increases corrosion it
 will reduce in life of the cylinder the overcome this
 problem refrigerant is heated superheated before it
 is send to compressor.

wet compression preferred for NH_3

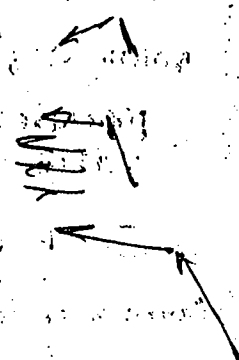
In Series Subcooler
the condenser temp height
increase



Liquid vapor H.E

(not cross)

In liquid vapor H.E subcooling of liquid
 refrigerating and superheating of the refrigerant
 vapor simultaneously as a result. $c.o.p$ increases
 as well as life cylinder increases.



HP no 3

HP no 3

HP no 3

Multi

when

flash
formation

NRE

NRE (KJ/kg)

$m \dot{r} (kg/kg)$

vol flow rate

η_{vol}

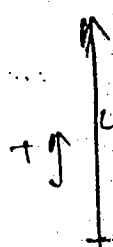
$W_{ck} (kg)$

$W_{ck} (kw)$

effe

Subco

a val



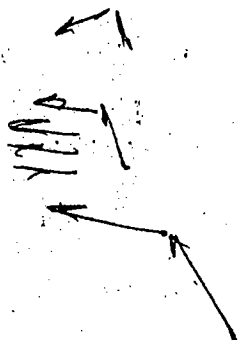
1) → page no (3)

↑ w_c (kw) ↓
now

the cylinder at well
front works.
motion it
become this
before it

ms

↑
liquid
refrigerant
p increases



Horse power per tonne of refrigeration

$$\text{HP/TR} = \frac{w'(\text{kw})}{Q'(\text{kw})}$$

$$= \frac{w^0}{0.746} \times \frac{1}{Q'(\text{TR})}$$

$$\boxed{\text{HP/TR} = \frac{4.72}{\text{C.O.P}}}$$

page No (4)

Multistage V.C System

When the difference between the evaporative and

flash gas % increases, cylindrical dimension ↑ evap's pressure ↓

NRE (kw) is always constant

NRE (kJ/kg) is always decreases

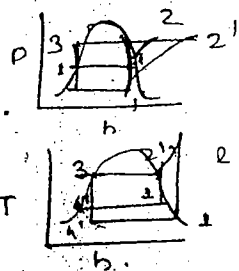
m_2 (kg/sec) ↓ v_1 (m³/kg) ↑

vol^m flow rate ↑ m_2 (kg/sec) pressure ↑
(m³/sec) ratio

η_{vol} ↓ cylindrical dimension decreases

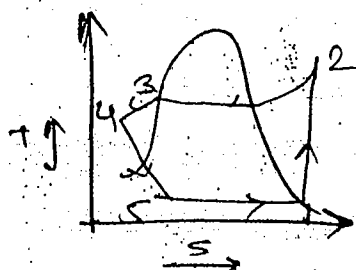
w_c (kw) ↑ w_c (kw) ↑ COP ↓ condenser load (kw) ↑

m_2 (kg/sec) ↑ change discharge temp ↑ flash gas %



Effect on Subcooling on a performance of a V.C

Subcooling is process by which the temp is reduced to a value less than the saturation temp



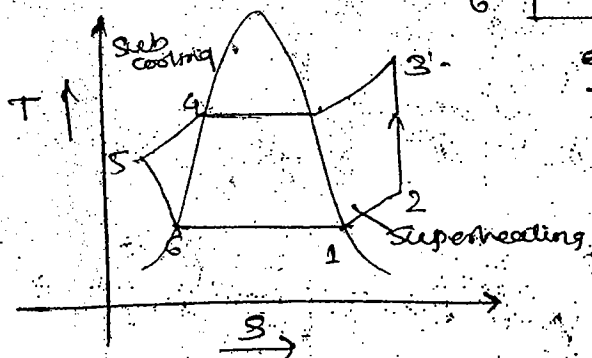
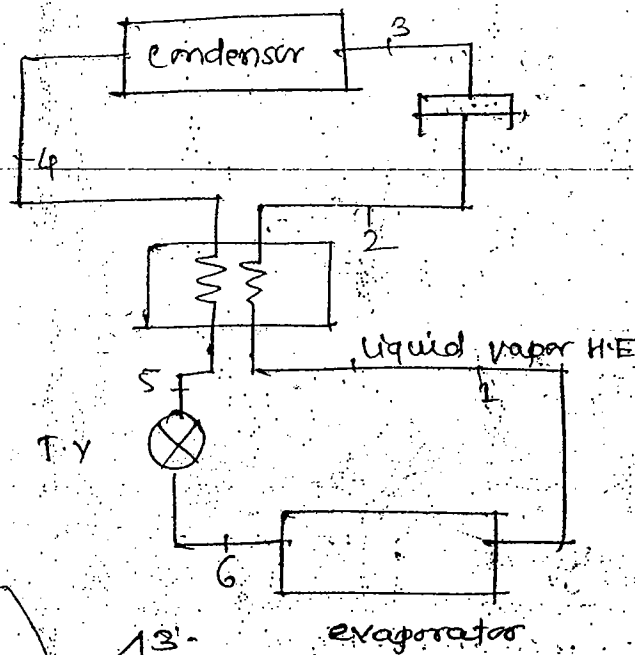
NRE (kw)

$$h_4 = h_3 - c_p (T_3 - T_4)$$

$$\boxed{h_5 = h_4}$$

(continued to
back page)

(8)



$$C_{pV}(T_2 - T_1) = C_{pL}(T_4 - T_5)$$

because of the liquid vapor heat exchanger the liquid leaving the condenser will have the condenser lower temp and refrigerant leaving evaporator has a higher temp.

Horse power per tonne of refrigeration

$$HP/TR = \frac{W \text{ (kW)}}{Q \text{ (kW)}}$$

$$= \frac{W}{0.746} \times \frac{1}{\frac{Q}{3.517} \text{ (TR)}}$$

$$\boxed{HP/TR = \frac{4.72}{C.O.P.}}$$

More

when
and
go to

- ① It
- ② Re
- ③ It
- ④ at

HP
out

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L.P.
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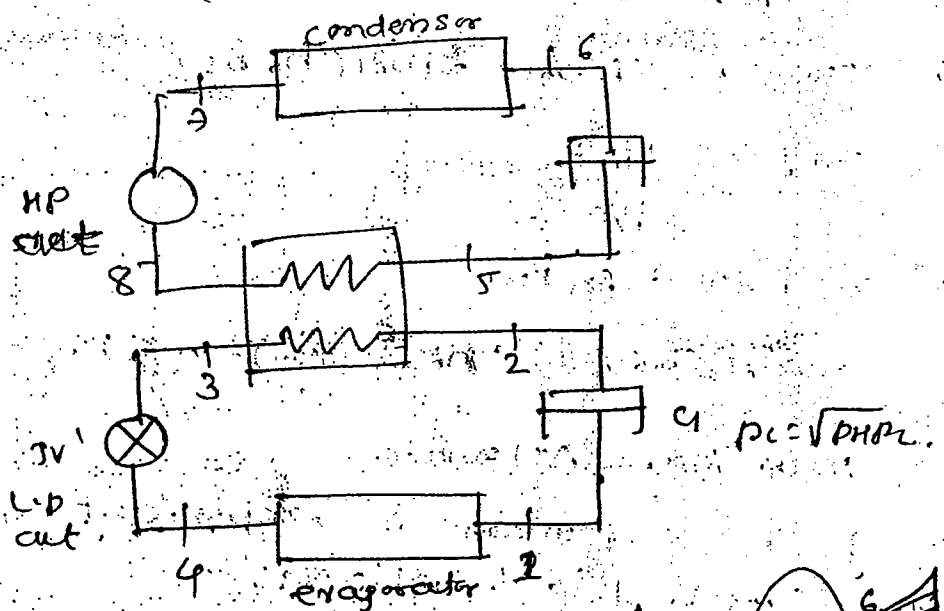
= N

↓

Multistage V.C. System

when the difference b/w the evaporative pressure and Condenser pressure is very high it is better to go for multistage comp'n system because

- ① It reduce the work of compression
- ② Reduce the compressor discharge temp.
- ③ Increase the volumetric efficiency
- ④ and increases the C.O.P of the system

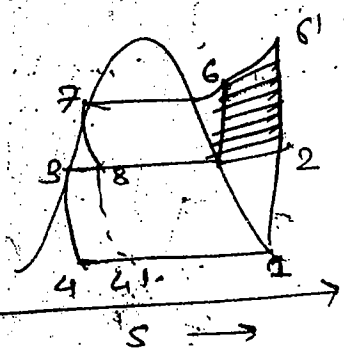


The evaporator of high pressure act as the condenser for the low pressure ckt.

$$\dot{m}_L \text{ (kg/sec)} (h_1 - h_4) \text{ W/kg.}$$

$$\dot{Q}_{NRE} \text{ (kW)} = 3.513 \times$$

$$\boxed{\dot{m}_L = \frac{3.513 \times}{h_1 - h_4} \text{ W/sec}}$$



Evaporator of high pressure cut
= Condenser of low cut

$$\dot{m}_H (h_5 - h_8) = \dot{m}_L (h_2 - h_3)$$

$$\dot{m}_H = \dot{m}_L \frac{(h_2 - h_3)}{(h_5 - h_8)}$$

$$(h_2 - h_3) > (h_5 - h_8)$$

$$\dot{m}_H > \dot{m}_L$$

$$W_C \text{ (kW)} = \dot{m}_L (h_2 - h_1) + \dot{m}_H (h_8 - h_5)$$

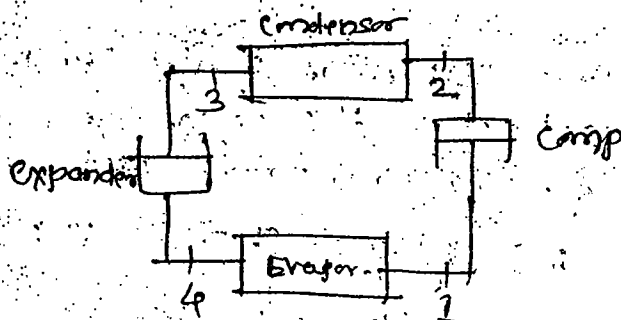
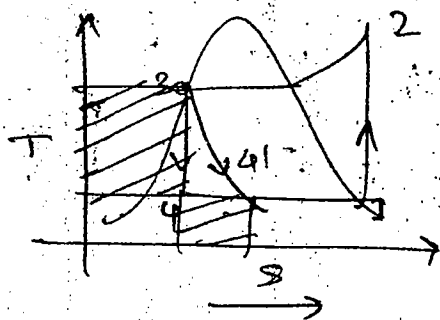
$$\text{C.O.P} = \frac{NRE}{W_C}$$

Condenser load in kW

$$= \dot{m}_H (h_6 - h_7) = hRE \text{ (kW)} + W_C \text{ (kW)} =$$

$$\dot{m}_w c_p w (\Delta T)_{\text{water}}$$

having an expander in a refrigerant circuit
when compared to throttle valve



$$W_C = h_2 - h_1$$

$$W_{\text{Expansion}} = (h_3 - h_4)$$

$$\uparrow \text{ If } W_{\text{net}} \downarrow = (W_C - W_E)$$

$$\text{then } \uparrow NRE = (h_1 - h_4)$$

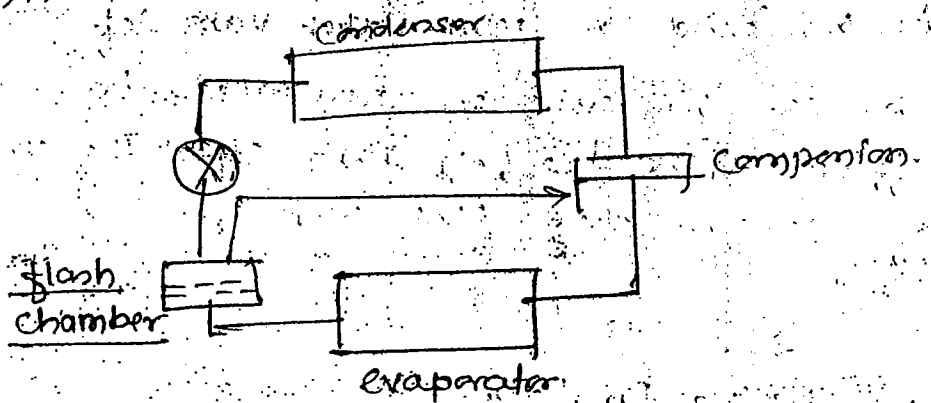
$$\text{C.O.P} = \uparrow$$

the
became
gained
hence
very
will
improvement
in
flash

Now
liquid
refrigerant
of
size
a
NRE
pro
of

The expansion stage in sat liquid line has because of friction and eddy losses whatever gain of work is there is lost in friction and hence the net advantage practically is very less.

Cost almost doubles and imbalances of will result will result in dynamic imbalanced hence expander is never incorporated in refrigeration cycle instead flash chamber.



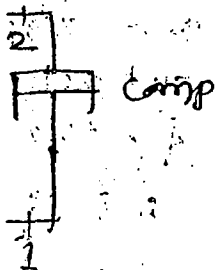
Now flash chamber separate vapor and liquid refrigerant and allows only liquid refrigerant to enter the evaporator and vapor refrigerant directly back to compressor. The size of evaporator decreases but provides a flash chamber does not having effect on NRE work of compression and COP.

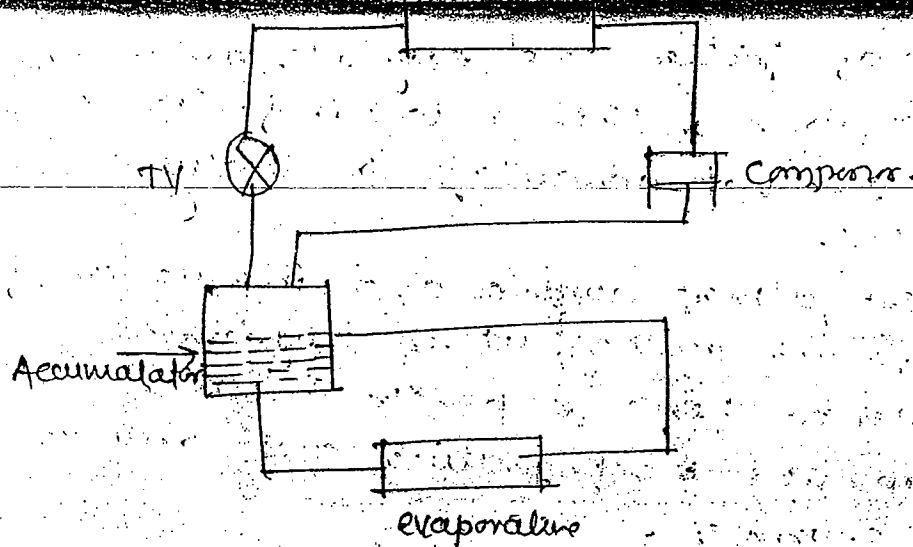
providing a accumulator in Ref. cycle providing a accumulator separated $\frac{1}{2}$ vol

2 liquid separated before evaporation is all as after evaporation

-(kw) =

out. c/f





By providing an accumulator vapour ref separated providing an accumulator has no effect on heat refrigerating effect the work of compression and the COP.

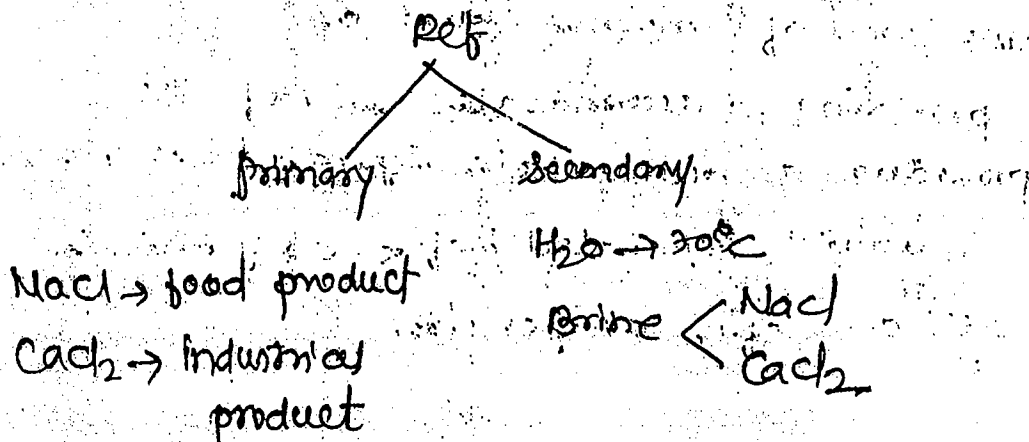
Refrigerant

having two type

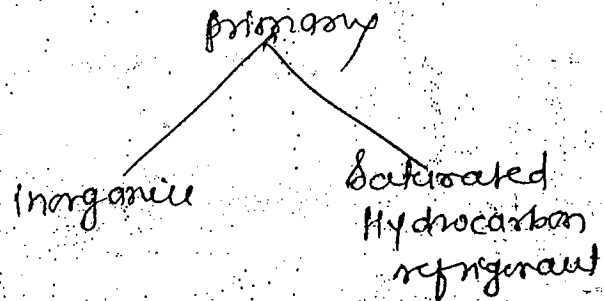
(I) primary

(II) Secondary

primary refrigerant take direct part in refrigerating action. Secondary refrigerants take indirect part in refrigerating action.



CaCl_2 provide have a dehydrated effect on food item hence they are not used



Inorganic ref are belong to 700 series
e.g. NH_3 , water sulphur dioxide
carbon dioxide

$$\text{NH}_3 \Rightarrow 700 + 12 = 712$$

$$\text{H}_2\text{O} \Rightarrow 700 + 18 = 718$$

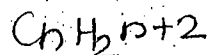
$$\text{SO}_2 \Rightarrow 700 + 64 = 764$$

$$\text{CO}_2 \Rightarrow 700 + 44 = 744$$

If molecular weight is added
700 we get the refrigerating number

n
refrigerants
of a/c

Saturated Hydrocarbon



Ref: $C_m H_n F_p Cl_q$

$$n + p + q = 2m + 2$$

n is hydrogen atom

p fluorine atom

q chlorine atom

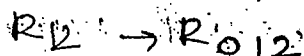
m carbon atom

Refrigerant no. $R(m+1)(n+1)P$

Chlorofluoro carbon

q → chlorine atom are causing ozone depletion potential

chlorine atoms are providing physiological stability and hydrogen atoms are causing flammability



$$p = F = 2$$

$$n+1=1, n=0, H_2=0$$

$$m-1=0, m=1, C$$

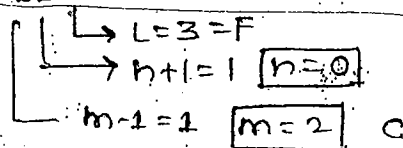
$$n + p + q = 2m + 2$$

$$0 + 2 + q = 2 \times 1 + 2$$

$$q = 2$$

The formula $CCl_2F_2 \rightarrow$ d. dichlorodifluoromethane

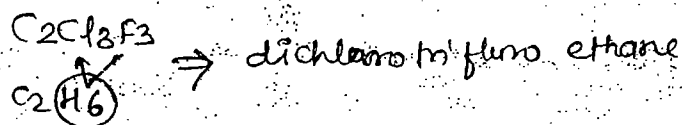
R113



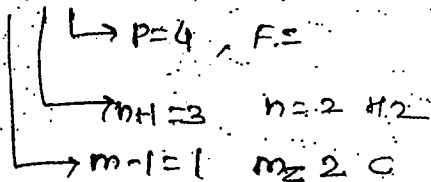
$$n+p+q = 2m+2$$

$$0+3+q = 2 \times 2 + 2$$

$$\boxed{q=3} \rightarrow Cl$$



R134



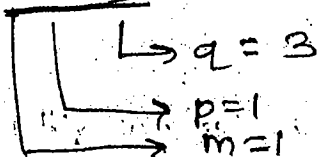
$$n+p+q = 2m+2$$

$$2+4+q = 2 \times 2 + 2$$

$$\boxed{q=0}$$

R134 & R134a have the same molecular formula but it different molecular formula arrangement here it is called isomers

CFCl₃:



$$n+p+q = 2m+2$$

$$n+1+3 = 2 \times 1 + 2$$

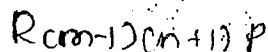
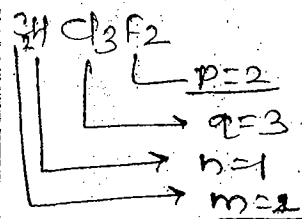
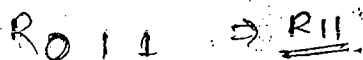
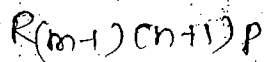
$$\boxed{n=0}$$

ption

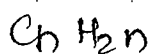
stability

lity

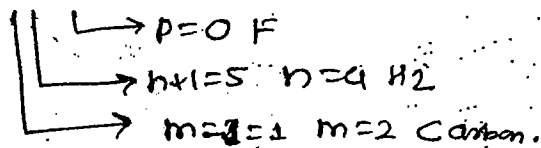
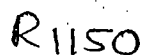
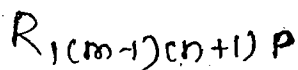
no methone



Unsaturated hydrocarbon series



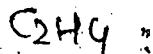
$$n+p+q=2m$$



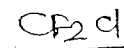
$$n+p+q=2m$$

$$4+0+q=2 \times 2$$

$$q=0$$

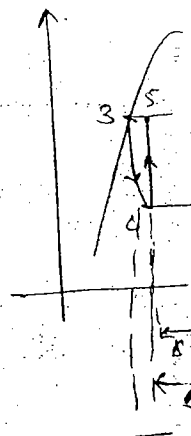


isobutane having formula R_{600} does not fit to nomenclature.



Bromination
bromine

Ewin



if con.
C.O.P.

C.O.P.

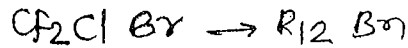
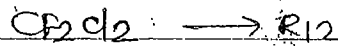
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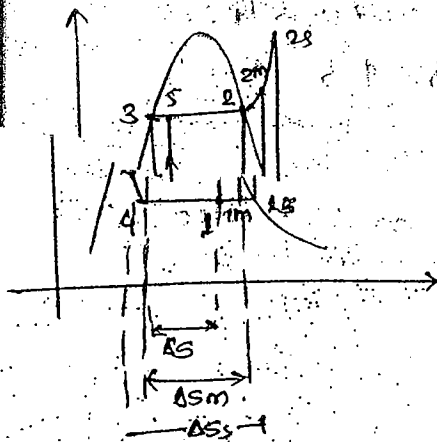
and

over



Brominating refrigerant the ~~last~~ chlorine atom replaced by bromine atom.

Ewings construction:



$$\text{C.O.P.} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{h_1 - h_4}{(h_2 - h_1) - (h_1 - h_4)}$$

$$= \frac{h_1 - h_4}{\Delta S}$$

$$\left(\frac{h_2 - h_4}{\Delta S} \right) - \left(\frac{h_1 - h_4}{\Delta S} \right)$$

$$= \frac{T_0}{\left(\frac{h_2 - h_4}{\Delta S} \right) - T_0}$$

if compression start at "4" NRE is "zero" and C.O.P is zero, AS we go from 4 to 1 NRE increases. C.O.P increases but work of compression almost same beyond "1" if we go the work of compression increases and we find that it continuous etc.

technically speaking the C.O.P. should decrease after 1, but it is found to increase upto 1.5 for certain substance and upto 1.5 for other substance this is because the slope $\frac{h_2 - h_4}{\Delta S_m}$

and $\frac{h_{2s} - h_4}{\Delta S_s}$ is minimum at 2m and 2s

respectively.

not fitted

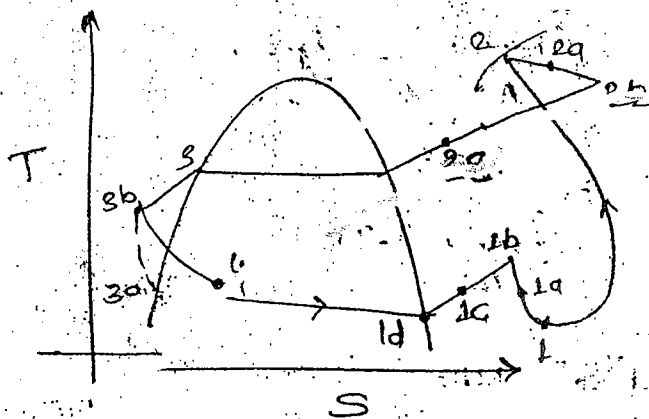
$$\text{hence C.O.P} = \frac{T_o}{T_m - T_o}$$

$$\text{C.O.P} = \frac{T_o}{T_s - T_o}$$

For certain substance wet compression preferred and for other substance superheated compression is preferred.

Wet compression is preferred for NH_3 or R_{11} & R_{22} and superheated compression is preferred for R_{12} isobutane and R_{134a} .

Deviations of VCR cycle from the ideally



1b-1c $\Rightarrow$ Superheating of vapor in the evaporator

1c-1b $\Rightarrow$ Heat gained and superheat of vapor at suction line

1b-1a $\Rightarrow$ pressure drop in suction line

1a-1 $\Rightarrow$ pressure drop due to throttling or wire drawing in the suction valve

1-2 $\Rightarrow$ polytropic compression

2-2a $\Rightarrow$ pressure drop in compressor discharge valve

2a-2b $\Rightarrow$ pressure drop in delivery line

2b-2c $\Rightarrow$ heat loss and desuperheating of vapor in delivery line.

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2c-3 $\Rightarrow$ pressure drop in condenser.

3-3d $\Rightarrow$ Subcooling in the condenser.

3a-3b $\Rightarrow$ heat gained in the liquid line

4-1d $\Rightarrow$ pressure drop in evaporator

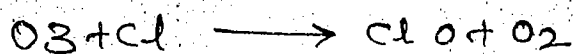
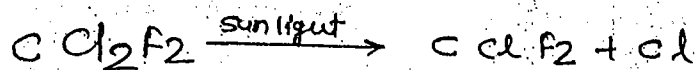
3b-4 $\Rightarrow$ throttling process (or) throttle valve.

Δp = pressure drop is basically momentum pressure drop
+ frictional pressure drop

In the condenser vapor refrigerant is getting converted to liquid refrigerant and momentum pressure drop is not where as frictional pressure drop is possible and pressure drop is less significant in the condenser. So and the evaporator liquid refrigerant is getting converted into the vapor refrigerant. velocity of vapor is more than liquid.

and momentum pressure drop & frictional pressure drop is possible. hence pressure drop is very significant in evaporator.

The evaporator can not be under design or over design as effect the performance very much and generally condenser is over design.



The conversion of ozone to oxygen is a serious problem as it is causing ozone depletion, and this leads to harmful radiation.

reaching the earth. hence chloroflouro carbon are gradually replaced with hydrochloroflouro carbon HFC and HFC

R12 replaced with R134a

R22 with R123

* Important point

- 1) pull down period
- 2) Ice making time

The time taken to bring the refrigerator from atm temp to evaporative temp is called as pull down period. if this period is less the refrigerator is good.

Ice making time :: the time required for converting water to ice is called as ice making

domestic compressor 11.7 mm dia
17.2 mm length

Page 41

$$\begin{aligned} \text{NRE} &= \frac{1}{5} \\ &= 1 \\ &= 5 \end{aligned}$$

$$\dot{m} \text{ kg/sec}$$

$$= \text{NRE}$$

$$\dot{m} \text{ (195)}$$

$$\dot{m}$$

$$\text{KIC (15)}$$

$$\text{KIC (15)}$$

$$\text{C.O.P.} =$$

ben are

than H₀c

prob 4.1 ex. 4

$$\begin{aligned} \text{NRE} &= 15 \text{ tons} \\ &= 15 \times 3.157 \text{ kW} \\ &= 52.75 \text{ kW} \end{aligned}$$

$$\begin{aligned} \dot{m}_2 (\text{kg/sec}) (h_1 - h_4) \text{ kJ/kg} \\ &= \text{NRE (kW)} \end{aligned}$$

$$\dot{m}_2 (195.7 - 64.6) = 52.75$$

$$\dot{m}_2 = 0.402 \text{ kg/sec}$$

$$h_c (\text{kJ/kg}) = \frac{n}{n-1} p_1 v_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{1.13}{1.13-1} \times 219 \times 0.082 \left[\left(\frac{9.6}{2.19} \right)^{\frac{1.13-1}{1.13}} - 1 \right]$$

$$= 28.92 \text{ kJ/kg}$$

$$h_c (\text{kW}) = \dot{m}_2 (\text{kg/sec}) h_c (\text{kJ/kg})$$

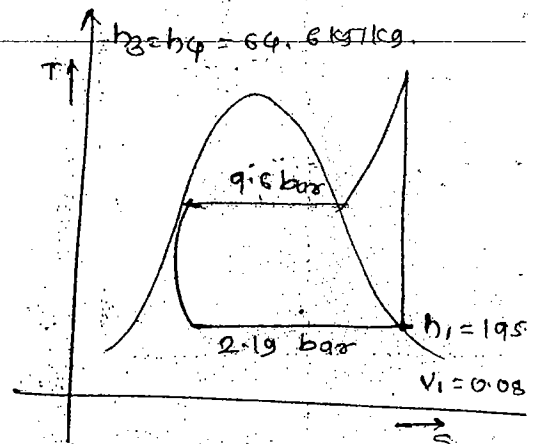
$$= 0.402 \times 28.92$$

$$= 11.63 \text{ kW}$$

$$\text{C.O.P} = \frac{\text{NRE (kW)}}{h_c (\text{kW})}$$

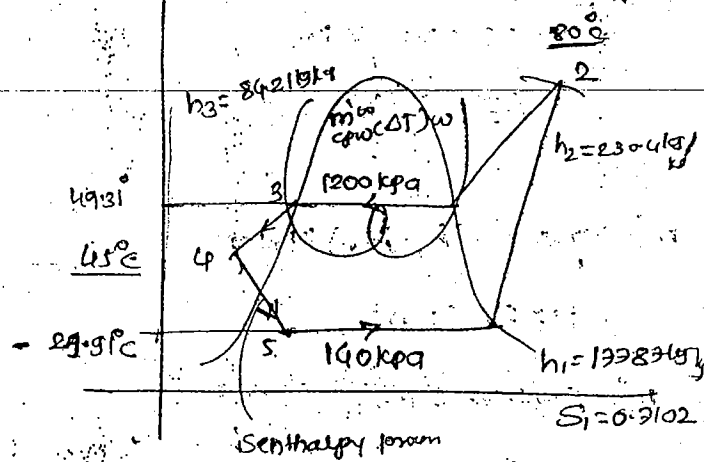
$$= \frac{52.75}{11.63}$$

$$= \underline{\underline{4.535}}$$



Q1.2 $\dot{m}_R = 0.2 \text{ kJ/sec}$

$c_{p, \text{liquid}} = 1 \text{ kJ/kg} \cdot \text{K}$



$$h_4 = h_3 - c_{p,l} (T_3 - T_4)$$

$$= 842.1 - 1 [493.1 - 45]$$

$$= 79.9 \text{ kJ/kg} = h_5$$

$$\text{NRE (kW)} = \dot{m}_R (\text{kg/sec}) (h_1 - h_4) \text{ kJ/kg}$$

$$= 0.2 (h_1 - h_4)$$

$$= 0.2 (177.87 - 79.9)$$

$$= 19.6 \text{ kW}$$

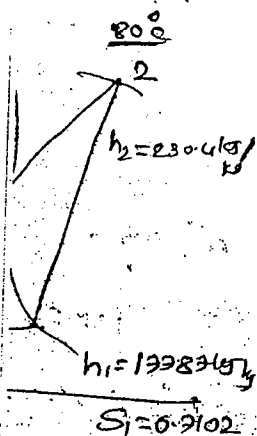
$$= \frac{19.6}{3.517} = 5.57 \text{ tonnes}$$

$$W_C (\text{kW}) = \dot{m} (\text{kg/sec}) (h_2 - h_1) \text{ kJ/kg}$$

$$= 0.2 (230.4 - 177.87)$$

$$= 10.50 \text{ kW}$$

$$\text{C.O.P} = \frac{\text{NRE (kW)}}{W_C (\text{kW})} = \frac{19.6}{10.5} = 1.86$$



$\dot{m}_w$

Heat gained by water = Heat lost in condenser

$$\dot{m}_w c_{pw} (\Delta T)_w = \dot{m}_g (kg/sec) (h_2 - h_4) \text{ kJ/kg}$$

$$\dot{m}_w \times 4.18 \times 10 = 0.2 (230.4 - 79.9) \text{ kJ}$$

$$\dot{m}_w = 0.72$$

$$S_1 = S_2$$

$$S_1 = S_2 = 0.7102$$

$$\begin{array}{ccc} 0.7514 & 230.4 & 0.7514 \\ & \leftarrow h_2 & \leftarrow 0.7102 \\ 0.7060 & 214.8 & 0.7060 \end{array}$$

$$\Delta h = 15.6 \quad \Delta S = 0.0454$$

$$\Delta h' = ?$$

$$\Delta S' = 0.0412$$

$$\Delta h' = \frac{\Delta S'}{\Delta S} \times \Delta h$$

$$230.4 - h_2 = \frac{0.0412}{0.0454} \times 15.6 =$$

$$h_2 = 216.8 \text{ kJ/kg}$$

$$\eta_c = \frac{W_s}{Q_a}$$

$$= \frac{h_2 - h_1}{h_2 - h_1}$$

$$= \frac{216.8 - 177.87}{230.4 - 177.87}$$

$$= \underline{0.73}$$

Q4.3 :

$$C.O.P = 6.5$$

$$W_c = 50 \text{ kW}$$

$$h_2' = 201.45 \text{ kJ/kg}$$

$$C_{p_v} = 0.06155 \text{ kJ/sec}$$

$$h_1 = 187.53 \text{ kJ/kg}$$

$$h_3 = h_4 = 69.5 \text{ kJ/kg}$$

$$C.O.P = 6.5$$

$$W_c = 50 \text{ kW}$$

$$C.O.P = \frac{NRE (\text{kJ})}{W_c (\text{kJ})}$$

$$6.5 = \frac{NRE}{50}$$

$$NRE = 325 \text{ kW}$$

$$\dot{m}_g \left(\frac{\text{kJ}}{\text{sec}} \right) (h_1 - h_4) \frac{\text{kJ}}{\text{kg}} = NRE (\text{kJ})$$

$$\dot{m}_g (187.53 - 69.5) = 325$$

$$\dot{m}_g = 2.759 \text{ kg/sec}$$

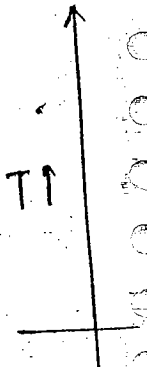
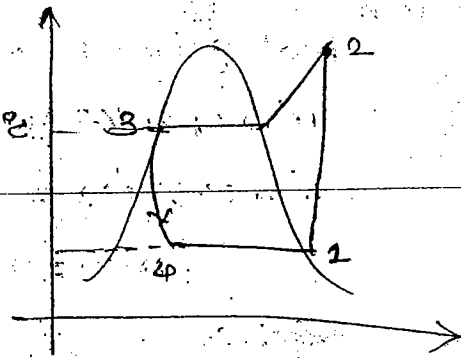
$$W_c (\text{kJ}) = \dot{m}_g \left(\frac{\text{kJ}}{\text{sec}} \right) (h_2 - h_1) \frac{\text{kJ}}{\text{kg}} =$$

$$50 = 2.759 \times (h_2 - 187.53)$$

$$h_2 = 205.67 \frac{\text{kJ}}{\text{kg}} = h_2' + C_{p_v} (T_2 - T_2')$$

$$205.67 = 201.45 + 0.06155 (T_2 - 35)$$

$$T_2 = 41.82^\circ\text{C}$$



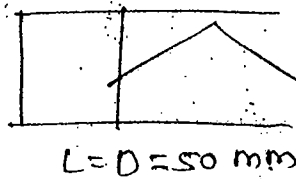
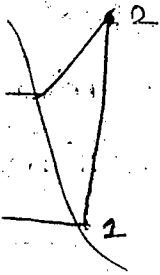
vol. mass

mass

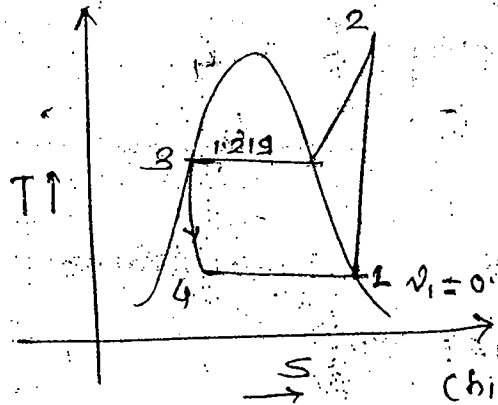
mass

NP

Q14



$N = 1460 \text{ rpm}$



$C = 0.05$

$n = 1.18$

$v_1 = 0.11 \frac{\text{m}^3}{\text{kg}}$

$(h_1 - h_4) = 94.7 \text{ kJ/kg}$

vol. mass flow rate $\dot{m} \text{ (kg/s)} = \dot{m}_2 \left(\frac{\text{kg}}{\text{sec}} \right) v_1 \left(\frac{\text{m}^3}{\text{kg}} \right)$

$$= \frac{\pi D^2 L n}{4} \times \frac{N}{60} \times \eta_{\text{vol}}$$

Theoretical stroke volume

= Theoretical stroke vol flow rate (m^3/s)

= Actual stroke vol flow rate (m^3/s)

$$= \frac{\pi D^2 L n}{4} \times \frac{N}{60} \times \left[1 + C - C \left(\frac{p_2}{p_1} \right)^{1/n} \right]$$

$$\dot{m}_2 (0.11) = \frac{\pi}{4} (50 \times 10^{-3})^2 (50 \times 10^3) \times 1$$

$$\times \frac{1460}{60} \left[1 + 0.05 - 0.05 \left(\frac{1.219}{0.11} \right)^{1/1.18} \right]$$

$$\dot{m}_2 (\text{kg/sec}) = 1.803 \times 0.016$$

(12)

(12-35)

$$\text{NRE (kW)} = \dot{m}_2 (\text{kg/sec}) (h_1 - h_4) (\text{kJ/kg})$$

$$= 0.016 \times 94.7$$

$$= 1.50 \text{ kW}$$

Qu. 5: NRE = 15 tons
 $= 15 \times 3.517 = 52.75 \text{ kW}$

$h_3 = h_4 = 263.3 \text{ kJ/kg}$

$h_1 = 407.1 \text{ kJ/kg}$

$v_1 = 0.0404 \frac{\text{m}^3}{\text{kg}}$

$\eta_{vol} = 0.72$

$\left(\frac{\pi}{4} D^2 L n \times \frac{N}{60} \right) = ?$

$\dot{m}_g \left(\frac{\text{kg}}{\text{sec}} \right) (h_1 - h_4) \frac{\text{kJ}}{\text{kg}} = \text{NRE (kW)}$

$\dot{m}_g (407.1 - 263.3) = 52.25$

$\boxed{\dot{m}_g = 0.366 \text{ kg/sec}}$

Vol flow rate (m^3/sec) = $\dot{m}_g \left(\frac{\text{kg}}{\text{sec}} \right) v_1 \left(\frac{\text{m}^3}{\text{kg}} \right)$

$= \frac{\pi}{4} D^2 L n \times \frac{N}{60} \times \eta_{vol}$

$= \alpha \times \text{ISVER (m}^3/\text{sec)}$

$= 0.366 \times 0.0404 = \alpha \times 0.72 \text{ m}^3/\text{sec}$

$\boxed{\alpha = 0.0205}$

if $L/D = 1.5$ and no. of cylinder = 5, $\text{rpm} = 900$

determine cylinder diameter.

$\frac{\pi}{4} \times D^2 \times 1.5D \times 1 \times \frac{900}{60} = 0.0205$

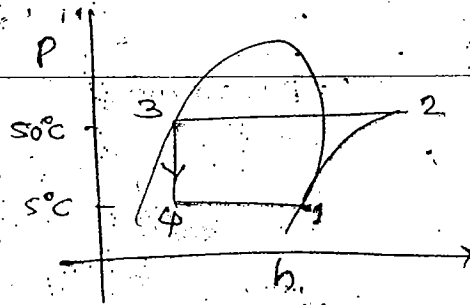
$D^3 =$

$D =$

$L =$

$h_3 = h_4$

Cool



η_v

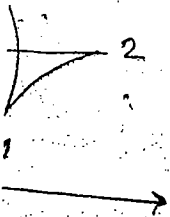
$\frac{\pi}{4}$

α

m

Vol

Qu. 7



Q4.6

$$h_3 = h_4 = 74.5 \text{ kJ/kg}$$

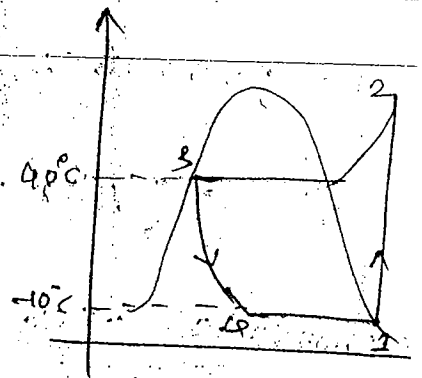
$$\text{Cooling load} = 0.15 \text{ kW}$$

$$N = 720 \text{ rpm}$$

$$\eta_{vol} = 0.8$$

$$\frac{\pi D^2 L n}{4} = ?$$

$\tau \cdot s \cdot v$



$$h_1 = 183 \text{ kJ/kg}$$

$$v = 0.08 \text{ m}^3/\text{kg}$$

$$\dot{m}_2 (\text{kg/sec}) (h_1 - h_4) \frac{10}{\text{kg}} = \text{NRE (kW)}$$

$$\dot{m}_2 (183 - 74.5) = 0.15$$

$$\dot{m}_2 = 0.00142 \text{ kg/sec}$$

$$\text{Vol}^m \text{ flow rate (m}^3/\text{sec)} = \dot{m}_2 (\text{kg/sec}) v_1 (\text{m}^3/\text{kg}) =$$

$$\frac{\pi D^2 L n}{4} \times \frac{1}{60} \times$$

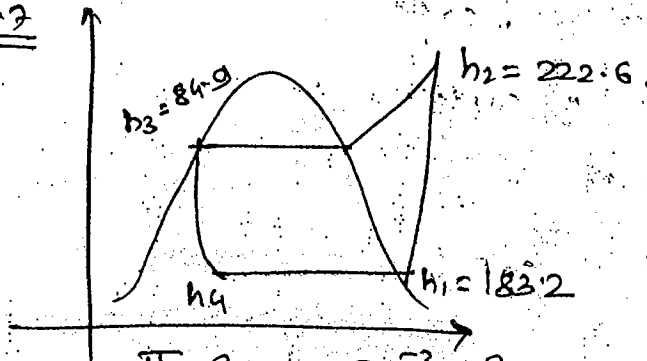
$$0.00142 \times 0.08 = x + \frac{720}{60} \times 0.8$$

$$x = 1.18 \times 10^5 \text{ m}^3$$

ec.

: qaw

Q4.7



$$\frac{\pi D^2 L n}{4} = 1.5 \times 10^3 \text{ m}^3$$

$$n = 1600 \text{ rpm}$$

$$\eta_{vol} = 0.8$$

$$v_1 = 0.0262 \text{ m}^3/\text{kg}$$

$$\text{Vol flow rate (m}^3/\text{sec)} = \dot{m}'_s (\text{kg/sec}) v_1 \left(\frac{\text{m}^3}{\text{kg}} \right)$$

$$\dot{m}'_s = \frac{\pi D^2 L n \times \frac{N}{60} \times h_{vol}}{60} \quad \frac{N}{60} = 26.67$$

$$\dot{m}'_s \times 0.0767 = 1.5 \times 10^3 \times 26.67 \times 0.8$$

$$\dot{m}'_s = 0.4192 \text{ kg/sec}$$

$$\text{NRE (kW)} = \dot{m}'_s (\text{kg/sec}) (h_1 - h_4) \text{ kJ/sec}$$

$$\begin{aligned} \text{NRE (kW)} &= \dot{m}'_s (h_1 - h_4) \\ &= 0.4192 (183.2 - 84.9) \\ &= 41.01 \end{aligned}$$

$$\text{Wc (kW)} = \dot{m}'_s (\text{kg/sec}) (h_2 - h_1) \text{ kJ/kg}$$

$$= 0.412 (222.6 - 183.2)$$

$$= 16.23$$

Small question:

Ques. 3 : $\text{C.O.P} = \frac{T_2}{T_1 - T_2}$

$$\left\{ \begin{array}{l} (T_1 - T_2) \downarrow \text{ C.O.P} \uparrow \\ T_1 \rightarrow T_2 \uparrow \quad (T_1 - T_2) \downarrow \text{ C.O.P} \uparrow \end{array} \right.$$

$$\left\{ \begin{array}{l} T_1 \uparrow \quad (T_1 - T_2) \uparrow \quad \text{C.O.P} \downarrow \\ T_2 \rightarrow \quad T_1 \uparrow \quad T_2 \downarrow \end{array} \right.$$

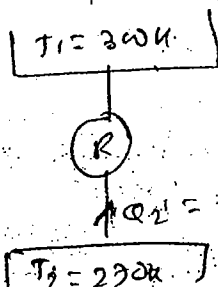
$$(T_1 - T_2) \uparrow \quad \text{C.O.P} \downarrow$$

$$1 \left(\frac{\text{m}^3}{\text{kg}} \right)$$

$$\frac{W}{68} = 26.69$$

Q111:

Min power is when c.o.p is max
and max c.o.p cannot c.o.p



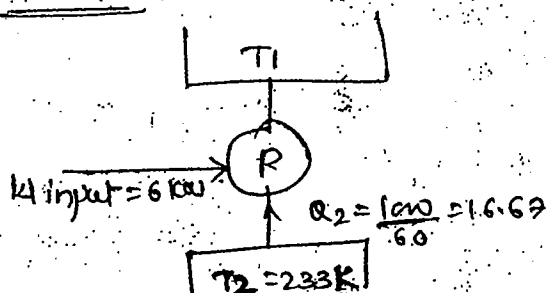
$$(c.o.p)_R = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

$$\frac{5 \times 10^6}{3600} = \frac{270}{300 - 270}$$

$$1388.89 =$$

$$W = 154.32 \text{ kW}$$

Q112:



$$c.o.p = \frac{Q_2}{W} = 2.7 \frac{T_2}{T_1 - T_2}$$

$$2.77 = \frac{233}{T_1 - 233}$$

$$2.77(T_1 - 233) = 233$$

$$2.77 T_1 = 317 \text{ or } 44^\circ \text{C}$$

(13)

$$\dot{m}_s (\text{kg/sec}) (h_1 - h_4) \frac{\text{kJ}}{\text{kg}} = 3.512 \text{ kW}$$

$$\dot{m}_s (h_1 - h_4) = 3.512$$

$$\dot{m}_s \times 105 = 3.512$$

$$\boxed{\dot{m}_s = 0.0233 \text{ kg/sec}}$$

NH_3 having max compression ratio than press.
in R