

~~XXXXXXXXXX~~

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The COP of a heat pump is greater than the COP of a refrigerator by unity.

The equation (2) expresses a very interesting feature of a heat pump,

Since, $Q_1 = [\text{COP}]_{\text{HP}} W$

$$Q_1 = [\text{COP}]_{\text{ref}} W$$

Hence it shows that the Q_1 is always greater than W in case of a heat pump.

~~XXXXXXXXXX~~

(a)

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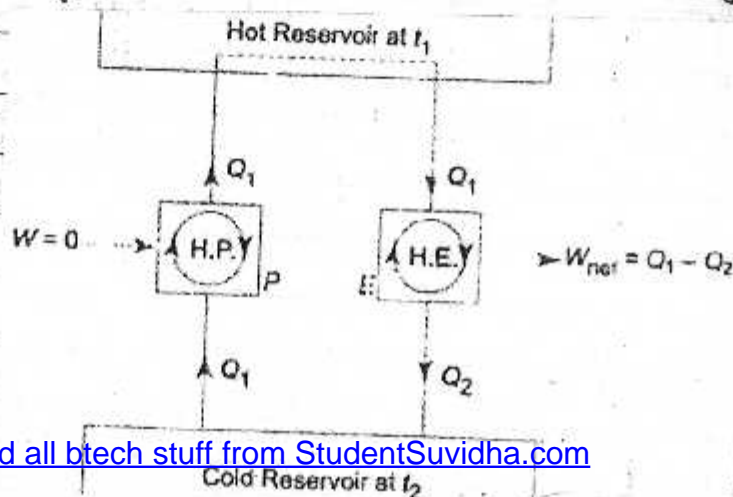
→ Equivalence Of Kelvin-Planck and Clausius Statements:-

At first sight, Kelvin-Planck's and Clausius Statements may appear to be unconnected, but it can easily be shown that they are virtually two parallel statements of the 2nd law and are equivalent in all respects.

The equivalence of the 2 statements will be proved if it can be shown that the violation of one statement implies the violation of the 2nd statement, and vice versa.

(a) Let us first consider a cyclic heat Pump 'P' which transfers heat from a low temperature reservoir (t_2) to a high temperature reservoir (t_1) with no other effect, i.e., with no expenditure of work, violating Clausius Statement. (Fig. A)

(Fig. A)



(49)

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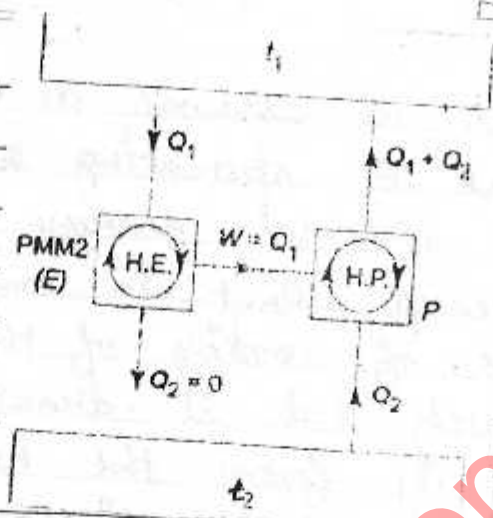
Let us assume a cyclic heat engine E operating between the same thermal energy reservoirs, producing W_{net} in one cycle. The state of working of the heat engine is such that it draws an amt. of heat Q_1 from the hot reservoir equal to that discharged by the heat pump. Then the hot reservoir may be eliminated and the heat Q_1 discharged by the heat pump is fed to the heat engine. So we see that heat pump 'P' and the heat engine 'E' acting together constitute a heat engine operating in cycle and producing net work while exchanging heat only with one body at a single fixed temperature. ~~For~~ Here this violates the Kelvin-Planck Statement.

(b) Let us now consider a PMMSE $\phi(E)$ which produces net work in a cycle by exchanging heat with only one thermal energy reservoir (at t_1) and thus violates the Kelvin-Planck Statement (Fig(b)).

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Fig (b)



Let us assume a cyclic heat pump 'P' extracting heat Q_2 from a low temperature reservoir at t_2 and discharging heat to the high temp. reservoir at t_1 with the expenditure of work 'W' equal to what PMMSE delivers complete cycle. So 'E' and 'P' together constitute a heat pump working in cycles and producing the sole effect of transferring heat from a lower to a higher temperature body, thus violating the Clausius statement.

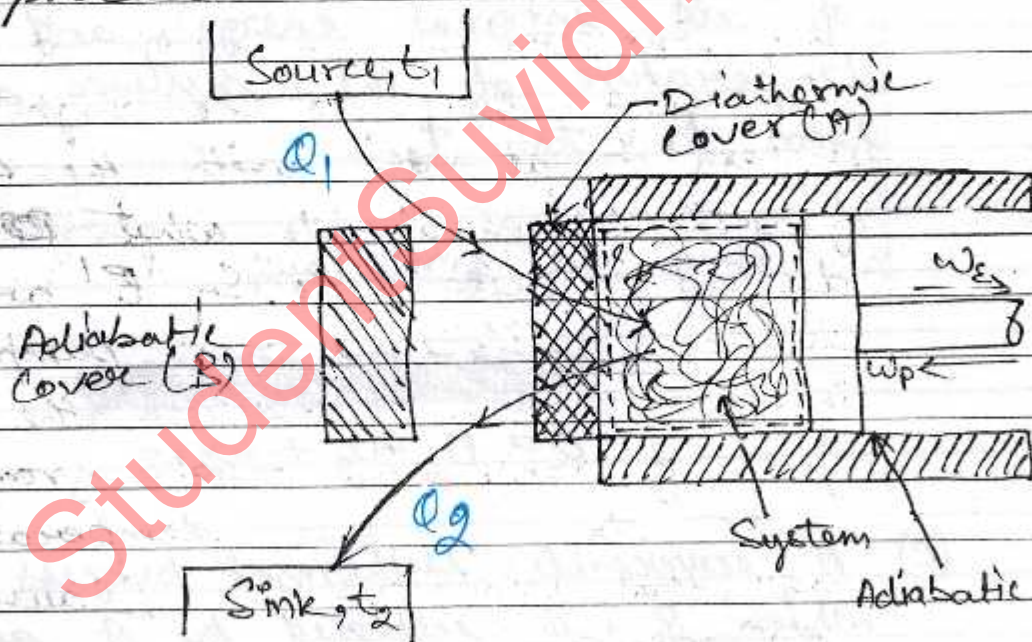
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⇒ CARNOT CYCLE:-

A reversible cycle is an ideal hypothetical cycle in which all the processes constituting the cycle are reversible. Carnot cycle is a reversible cycle. For a stationary system, as in a piston and cylinder machine, the cycle consists of the following four successive processes.



- (a) A reversible isothermal process in which heat Q_1 enters the system at t_1 reversibly from a constant temperature source at t_1 when the cylinder cover is in contact with the diathermic cover A. The internal

energy of the system increases.
From first law,

an
which
cycle
a

$$Q_1 = U_2 - U_1 + W_{1-2} \quad \text{--- (1)}$$

(for an ideal gas only, $U_1 = U_2$)

(B) A reversible adiabatic process in which the diathermic cover A is replaced by the adiabatic cover B, and work W_2 is done by the system adiabatically and reversibly at the expense of its internal energy, and the temperature of the system decreases from t_1 to t_2 .

Using the first law;

~~$$Q = U_3 - U_2 + W_{2-3}$$~~

$$0 = U_3 - U_2 + W_{2-3} \quad \text{--- (2)}$$

(C) A reversible isothermal process in which B is replaced by A and heat Q_2 leaves the system at t_2 to a constant temperature sink at t_2 reversibly, and the internal energy of the system further decreases.

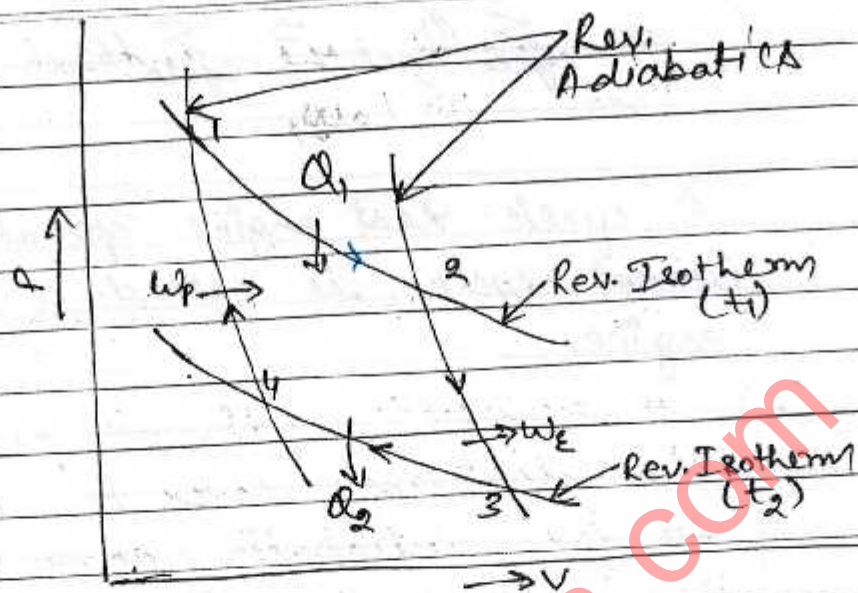
From first law;

$$-Q_2 = U_4 - U_3 - W_{3-4} \quad \text{--- (3)}$$

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- (d) A reversible adiabatic process in which B again ~~replaces~~ ~~replaces~~ replaces by A, and work W_p is done upon the system reversibly and adiabatically, and the internal energy of the system increases and the temperature rises from T_2 to T_1 .
Again applying the first law;

$$0 = W_1 - W_2 - W_3 - W_4 \quad \text{--- (1)}$$

Two reversible isotherms and two reversible adiabatics constitute a Carnot cycle, which is represented in p-v coordinates above.

Summing up eq. (1), (2), (3) & (4);

$$Q_1 - Q_2 = (W_{1-2} + W_{2-3}) - (W_{3-4} + W_{4-1})$$

(34)

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H.C.A

$$\text{or } \sum_{\text{cycle}} Q_{\text{net}} = \sum_{\text{cycle}} W_{\text{net}}$$

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(1)

A cyclic heat engine operating on the Carnot cycle is called a Carnot heat engine.

H.C.M
(2)

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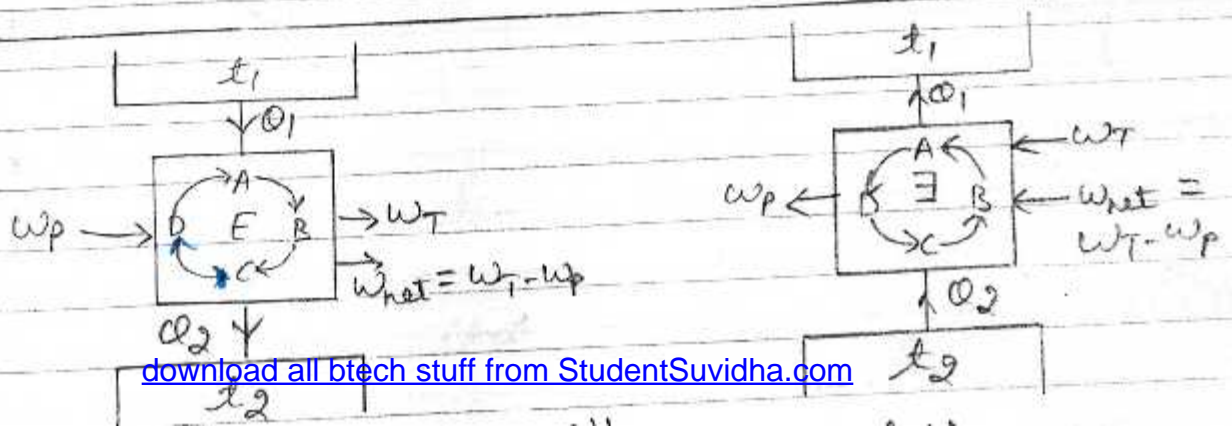
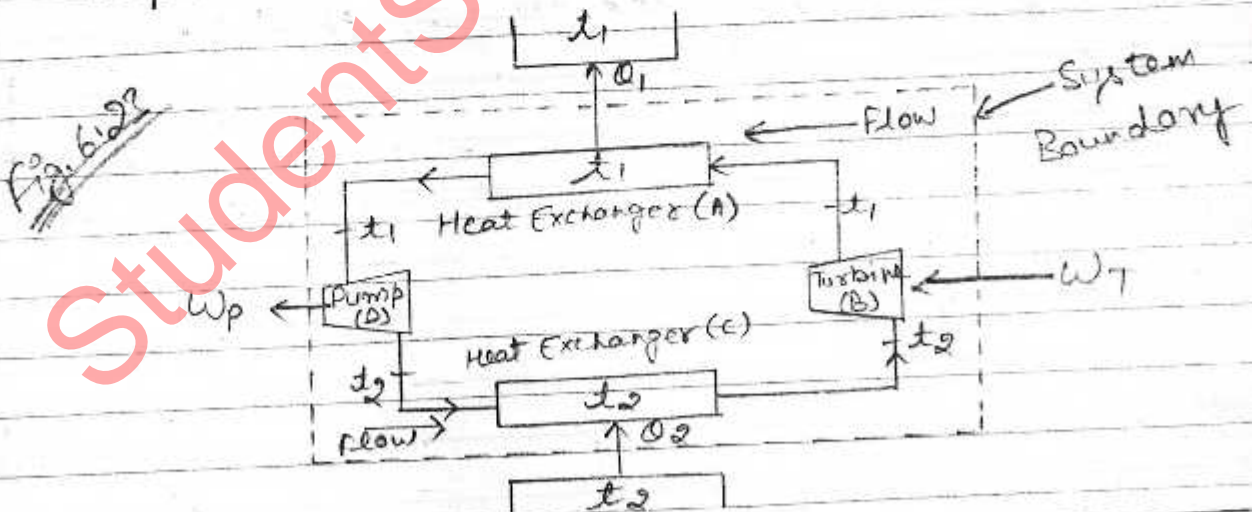
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3-4 + W₄₋₁

⇒ REVERSED HEAT ENGINE (CARNOT HEAT PUMP):-

Since all the processes of the Carnot cycle are reversible, it is possible to ~~imagine~~ imagine that the processes are individually reversed and carried out in reversed order. When a reversible process is reversed, all the energy transfer associated with the process are reversed in direction, but remain the same in magnitude. The reversed Carnot cycle for a steady-state fluid system is shown in Fig. 6.23. The reversible heat engine and the reversed Carnot heat engine are represented in block diagrams in Fig. 6.24.



If E is a reversible heat engine (Fig. 6.24a), and if it is reversed (Fig. 6.24b), the quantities Q_1 , Q_2 and W remain the same in magnitude, and only their directions are reversed. The reversed heat engine E takes heat from a low temperature body, discharges heat to a high temperature body, and receives an inward flow of network.

The names HEAT PUMP and REFRIGERATOR are applied to the reversed heat engine, which have already discussed previously, where the working fluid flows through the compressor (B), condenser (A), expander (D) and evaporator (C) to complete the cycle.

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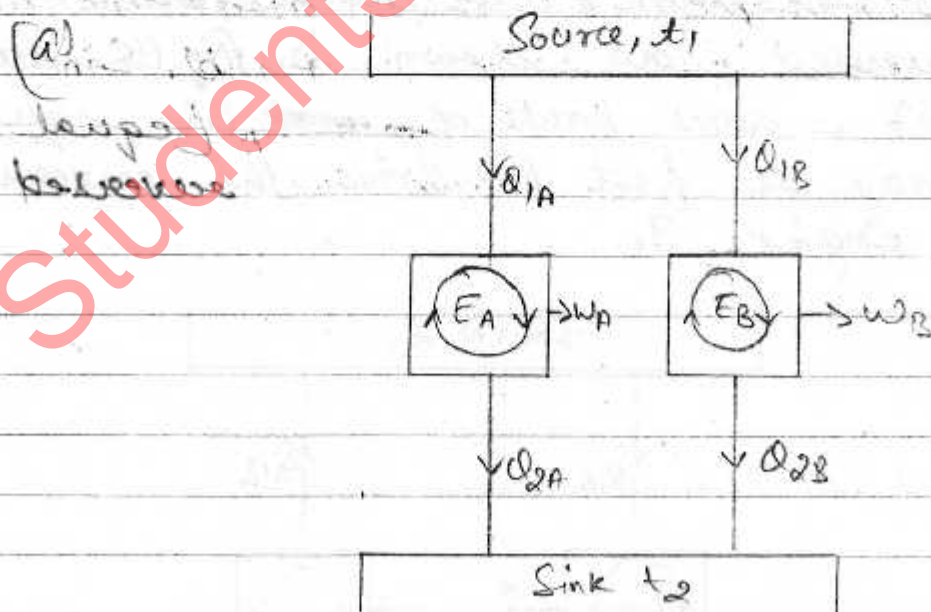
 \Rightarrow CARNOT'S THEOREM:-

It states that of all heat engines operating between a given constant temperature source and a given constant temperature sink, none has a higher efficiency than a reversible engine.

OR

Working between same temperature limits, no engine can be more efficient than a reversible engine.

Let two heat engines E_A and E_B operate between the given source at temperature t_1 and the given sink at temperature t_2 as shown in Fig (a).



Let E_A be any heat engine and E_B ~~operate~~ be any reversible heat engine. We have to prove that the efficiency of E_B is more than that of E_A . Let us assume

(58)

that this is not true and $\eta_A > \eta_B$. Let the scales of working of the engines be such that

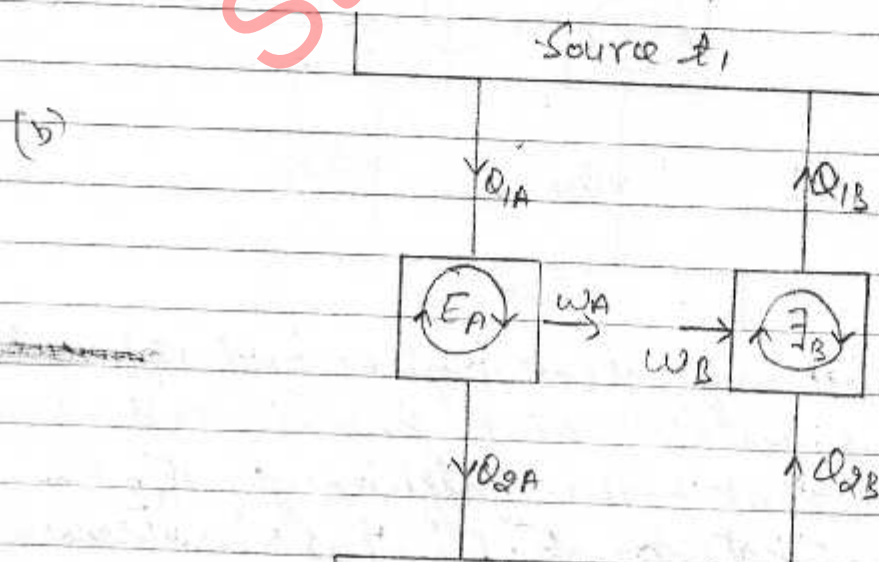
$$Q_{1A} = Q_{1B} = Q_1$$

Since $\eta_A > \eta_B$

$$\frac{W_A}{Q_{1A}} > \frac{W_B}{Q_{1B}}$$

$$W_A > W_B$$

Now let E_B be reversed. Since E_B is a reversible heat engine, the magnitudes of heat and work transfer quantities will remain the same, but their directions will be reversed, as shown in Fig (b). Since $W_A > W_B$, some part of W_A (equal to W_B) may be fed to drive the reversed heat engine E_B .



(59)

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such

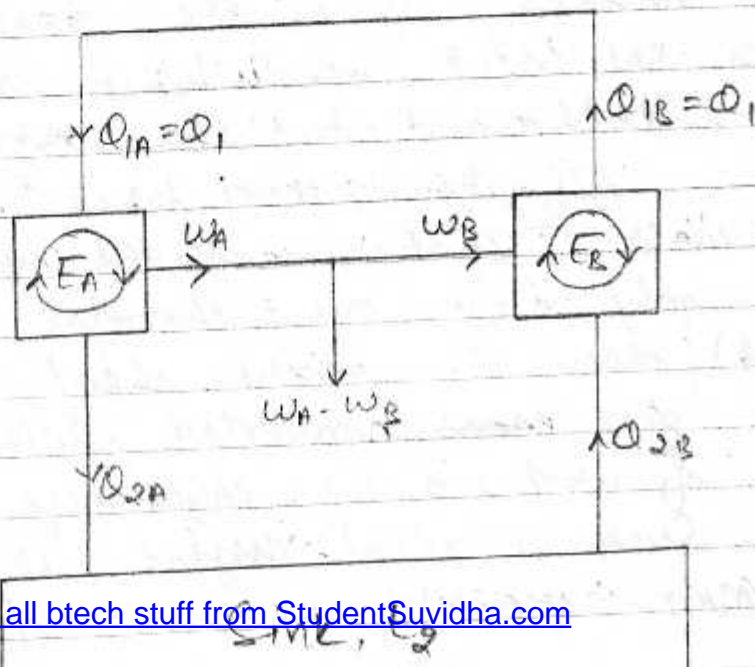
Since $Q_{1A} = Q_{1B} = Q_1$, the heat discharged by E_B may be supplied to E_A . The source may, therefore, be eliminated (Fig. c). The net result is that E_A and E_B together constitute a heat engine which, operating in cycle, produces net work $W_A - W_B$, while exchanging heat with a single reservoir at T_2 . This violates the Kelvin-Planck statement of the second law. Hence the assumption that $\eta_A > \eta_B$ is wrong.

Therefore $\eta_B \geq \eta_A$

⇒ Corollary of Carnot's Theorem :-

All reversible engines working b/w same temperature limits will have same efficiencies.

(c)



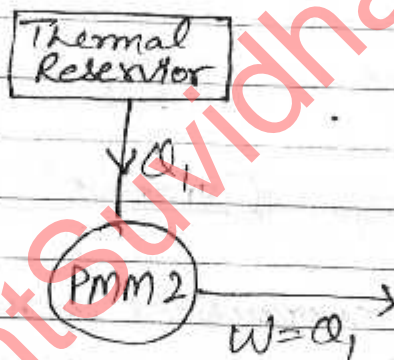
(60)

⇒ PMM2K :-

A practical heat engine exchanges heat with two thermal reservoirs (source and sink) and its thermal efficiency is given by :-

$$\eta_H = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

(Fig. A)



where Q_1 is the heat supplied from the source, Q_2 is the heat rejected to the sink and W_{net} is the net work delivered to the surroundings.

If $Q_2 = 0$, then $W_{net} = Q_1$ and

$\eta_H = 100\%$. That is, if the engine exchanges heat only with one thermal reservoir (Fig. A), then the entire heat supplied to it gets ~~com~~ converted into an equivalent amt. of work & the efficiency becomes 100%. Such a heat engine is called PMM2.

The PMM2 operates in the conformity of with

(G1)

the first law, but it violates the Kelvin-Planck statement of 2nd law. As such it is only of hypothetical interest and cannot be ~~not~~ realized in practice.

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(62)

⇒ Thermodynamic Temperature Scale:-

The efficiency of any heat engine cycle receiving heat Q_1 and rejecting heat Q_2 is given by;

$$\eta = \frac{W_{\text{net}}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \quad \text{--- (1)}$$

By the 2nd law, it is necessary to have a temp. difference ($t_1 - t_2$) to obtain work of any cycle. We know that the efficiency of all heat engines operating b/w the same temp. levels is the same, and it is independent of the working substance. Therefore, for a reversible cycle (Carnot cycle), the efficiency will depend solely upon the temp. t_1 and t_2 , at which heat is transferred, or

$$\eta_{\text{rev.}} = f(t_1, t_2) \quad \text{--- (2)}$$

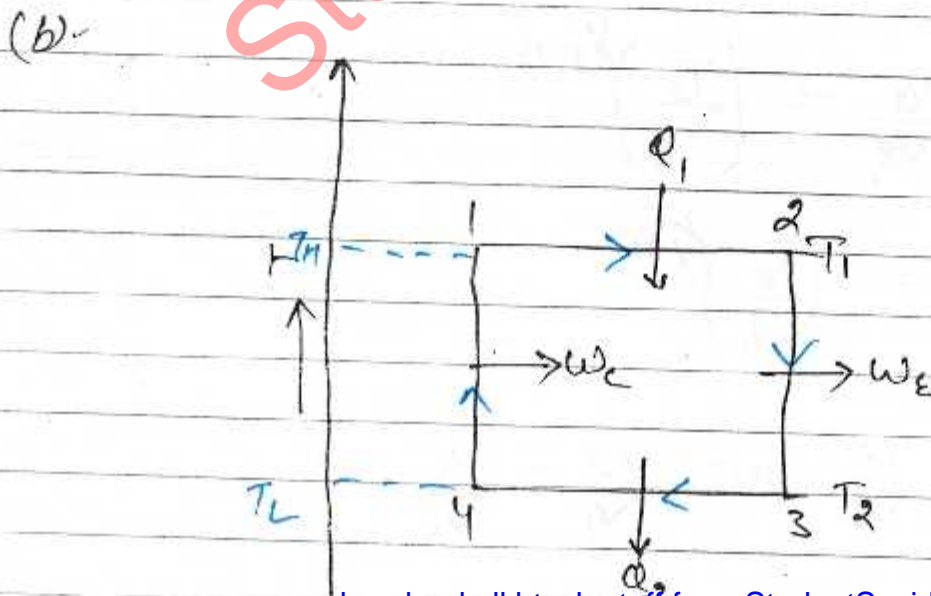
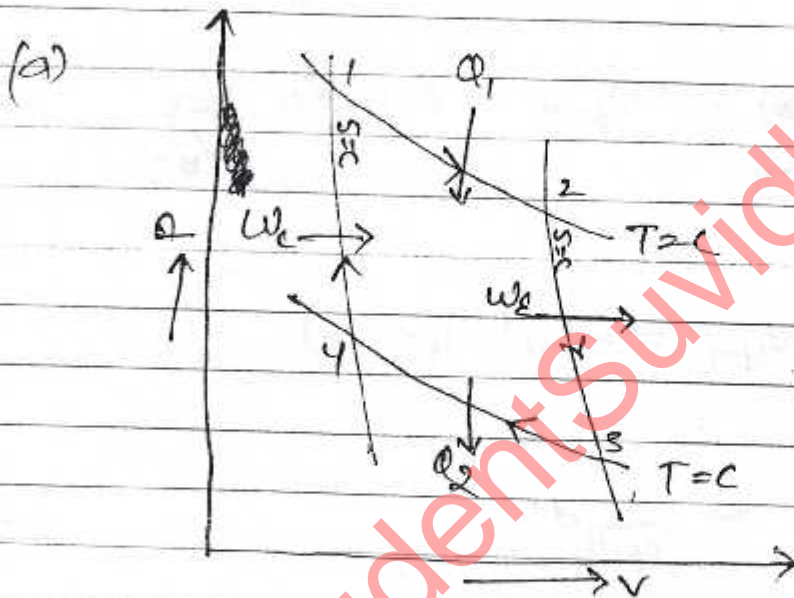
where f signifies some function of the temperatures. From eq. (1) & (2);

$$1 - \frac{Q_2}{Q_1} = f(t_1, t_2)$$

(63)

⇒ CARNOT CYCLE :-

The Carnot cycle consists of two reversible isotherms and two reversible adiabatics. If an ideal gas is assumed as the working fluid, then for 1kg of gas;



(64)

~~Q₁₋₂ = RT₁ ln V₂/V₁ ; W₁₋₂ = RT₁ ln V₂/V₁~~

of
two
gas
then

$$Q_{1-2} = RT_1 \ln \frac{V_2}{V_1} ; W_{1-2} = RT_1 \ln \frac{V_2}{V_1}$$

$$Q_{2-3} = 0 ; W_{2-3} = -C_v (T_3 - T_2)$$

$$Q_{3-4} = RT_2 \ln \frac{V_4}{V_3} ; W_{3-4} = RT_2 \ln \frac{V_4}{V_3}$$

$$Q_{4-1} = 0 ; W_{4-1} = -C_v (T_1 - T_4)$$

$$\therefore \sum_{\text{cycle}} dQ = \sum_{\text{cycle}} dW$$

Now,

$$\frac{V_2}{V_3} = \left(\frac{T_2}{T_1} \right)^{\frac{1}{\gamma-1}}$$

and $\frac{V_1}{V_4} = \left(\frac{T_2}{T_1} \right)^{\frac{1}{\gamma-1}}$

$$\therefore \frac{V_2}{V_3} = \frac{V_1}{V_4} \quad \text{or} \quad \frac{V_2}{V_1} = \frac{V_3}{V_4}$$

(65)

Therefore,

$$Q_1 = \text{Heat added} = RT_1 \ln \frac{V_2}{V_1}$$

$$W_{\text{net}} = Q_1 - Q_2 = R \ln \frac{V_2}{V_1} (T_1 - T_2)$$

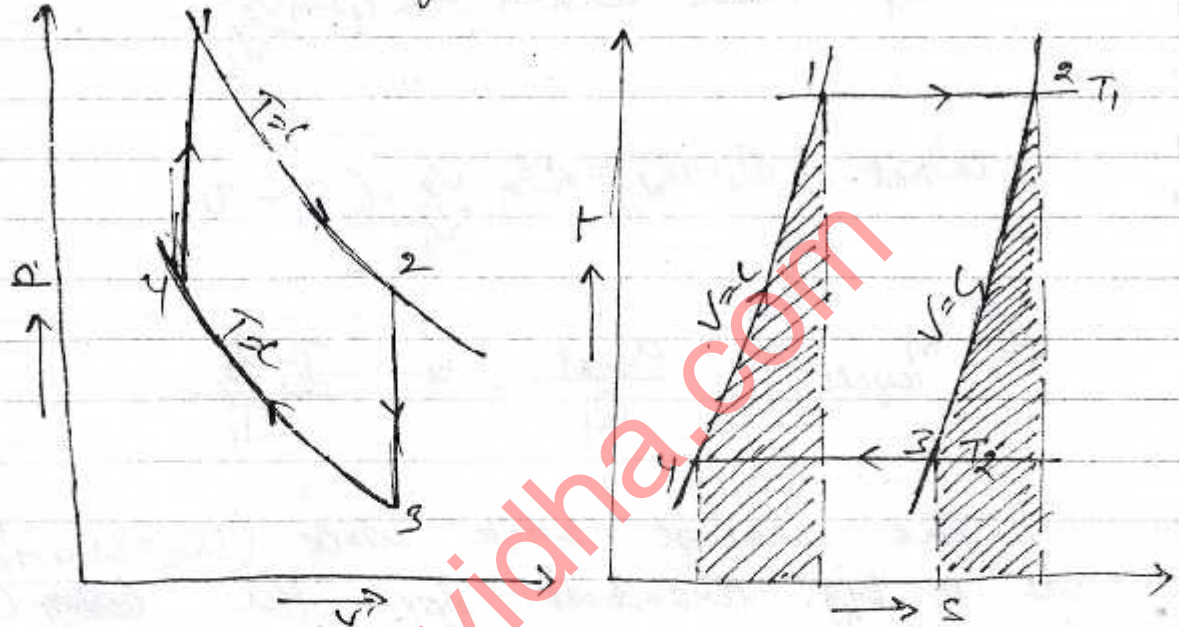
$$\therefore \eta_{\text{cycle}} = \frac{W_{\text{net}}}{Q_1} = \frac{T_1 - T_2}{T_1}$$

The large back work ($W_c = W_4 - 1$) is a big drawback for the ~~Carnot~~ Carnot Gas cycle, as in the case of the Carnot vapour cycle.

(66)

⇒ STIRLING CYCLE:-

The Stirling consists of;



1-2)
→ Carnot

Two reversible isotherms and two reversible isochores. For 1 kg of ideal gas,

$$Q_{1-2} = W_{1-2} = RT_1 \ln \frac{V_2}{V_1}$$

$$Q_{2-3} = -C_V(T_2 - T_1); W_{2-3} = 0$$

$$Q_{3-4} = W_{3-4} = RT_2 \ln \frac{V_3}{V_4}$$

$$Q_{4-1} = C_V(T_1 - T_2); W_{4-1} = 0$$

(67)

Due to heat transfers at constant volume processes, the efficiency of the Stirling cycle is less than that of the Carnot cycle. However, if a ~~reener~~ regenerative arrangement is used such that

$$Q_{2-3} = Q_{4-1}$$

i.e., the area under 2-3 is equal to the area under 4-1, then the cycle efficiency becomes,

$$\eta = \frac{RT_1 \ln \frac{V_2}{V_1} - RT_2 \ln \frac{V_3}{V_4}}{RT_1 \ln \frac{V_2}{V_1}} = \frac{T_1 - T_2}{T_1}$$

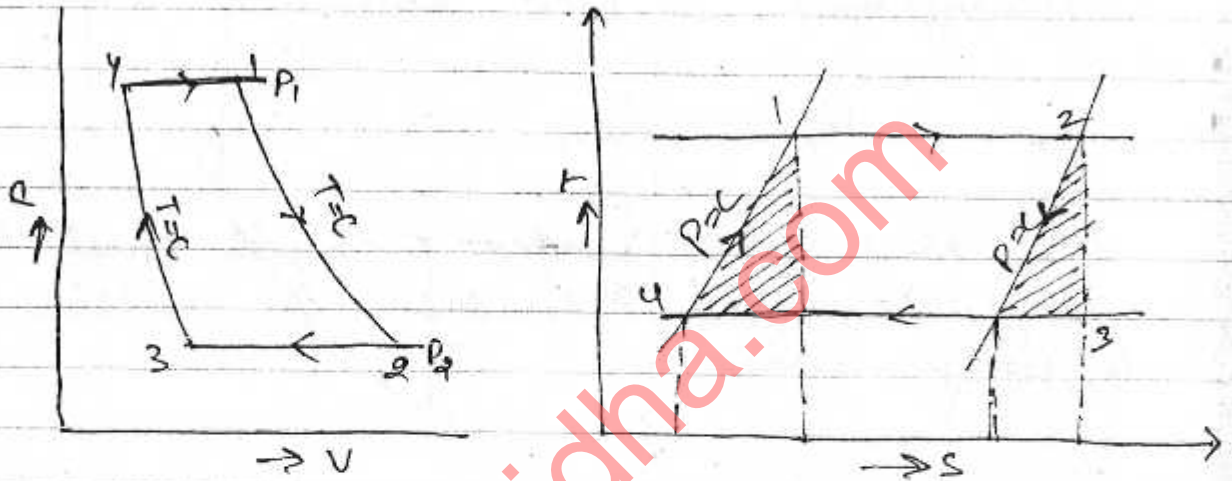
So, the regenerative Stirling cycle has the same efficiency as the Carnot cycle.

(68)

volume

→ ERICSSON CYCLE ;ng
Carnot
ative

The Ericsson Cycle is made of ;



Two reversible isotherms and two reversible isobars for 1 kg ideal gas,

$$Q_{1-2} = W_{1-2} = R T_1 \ln \frac{P_1}{P_2}$$

$$Q_{2-3} = C_p (T_2 - T_1); W_{2-3} = P_2 (V_3 - V_2) = R (T_2 - T_1)$$

$$Q_{3-4} = W_{3-4} = -R T_2 \ln \frac{P_1}{P_2}$$

$$Q_{4-1} = C_p (T_1 - T_2); W_{4-1} = P_1 (V_1 - V_4) = R (T_1 - T_2)$$

Since part of the heat is transferred at constant pressure and part at constant temperature, the efficiency of the Ericsson

cycle is less than that of Carnot cycle. But with ideal regeneration, $Q_{2-3} = Q_{4-1}$, so that all the heat is added from the external source at T_1 and all the heat is rejected to an external sink at T_2 , the efficiency of the cycle becomes equal to the Carnot cycle efficiency, since,

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{RT_2 \ln \frac{P_1}{P_2}}{RT_1 \ln \frac{P_1}{P_2}} = 1 - \frac{T_2}{T_1}$$

The regenerative, Stirling and Ericsson cycles have the same efficiency as the Carnot cycle, but much less back work. Hot air engines working on these cycles have been successfully operated. But it is difficult to transfer heat to a gas at high rates since the gas film has a very low thermal conductivity. So there has not been much progress in the development of hot air engines. However, since the cost of internal combustion engine fuels is getting excessive, these may find a field of use in the near future.

Fuel -
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Ignition
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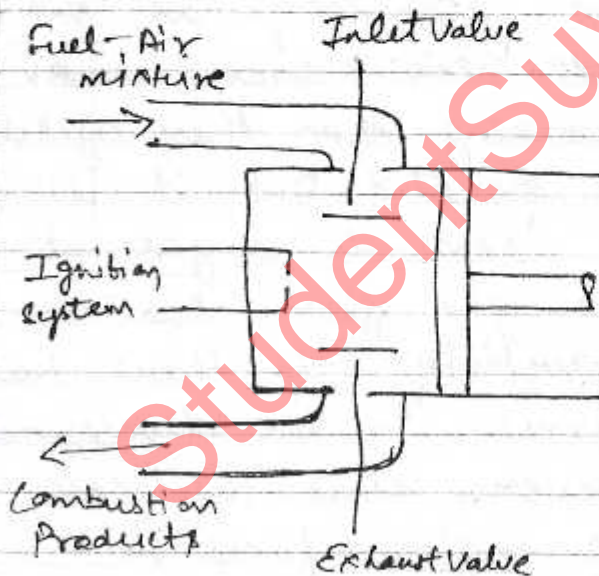
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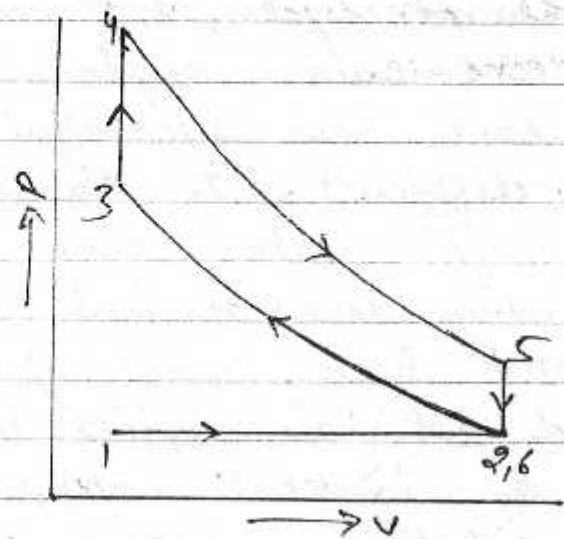
move
into

⇒ OTTO CYCLE:-

One very common type of internal combustion engines is the Spark Ignition (S.I.) engine used in automobiles. The Otto cycle is the air standard cycle of such an engine. The sequence of processes in the elementary operation of the S.I. engine is given below, with reference to Fig (a & b) where the sketches of the engine and the indicator diagram are given.



(a)



(b)

Process 1-2:- Intake

The inlet valve is open, the piston moves to the right, admitting fuel-air mixture into the cylinder at constant pressure.

(71)

Process 2-3:- Compression,

Both the valves are ~~also~~ closed, the piston compresses the combustible mixture to the minimum volume.

Process 3-4:- Combustion,

The mixture is then ignited by means of a spark, combustion takes place, and there is an increase in temperature & pressure.

Process 4-5:- Expansion,

The products of combustion do work on the piston which moves to the right, and the pressure and temperature of the gases decrease.

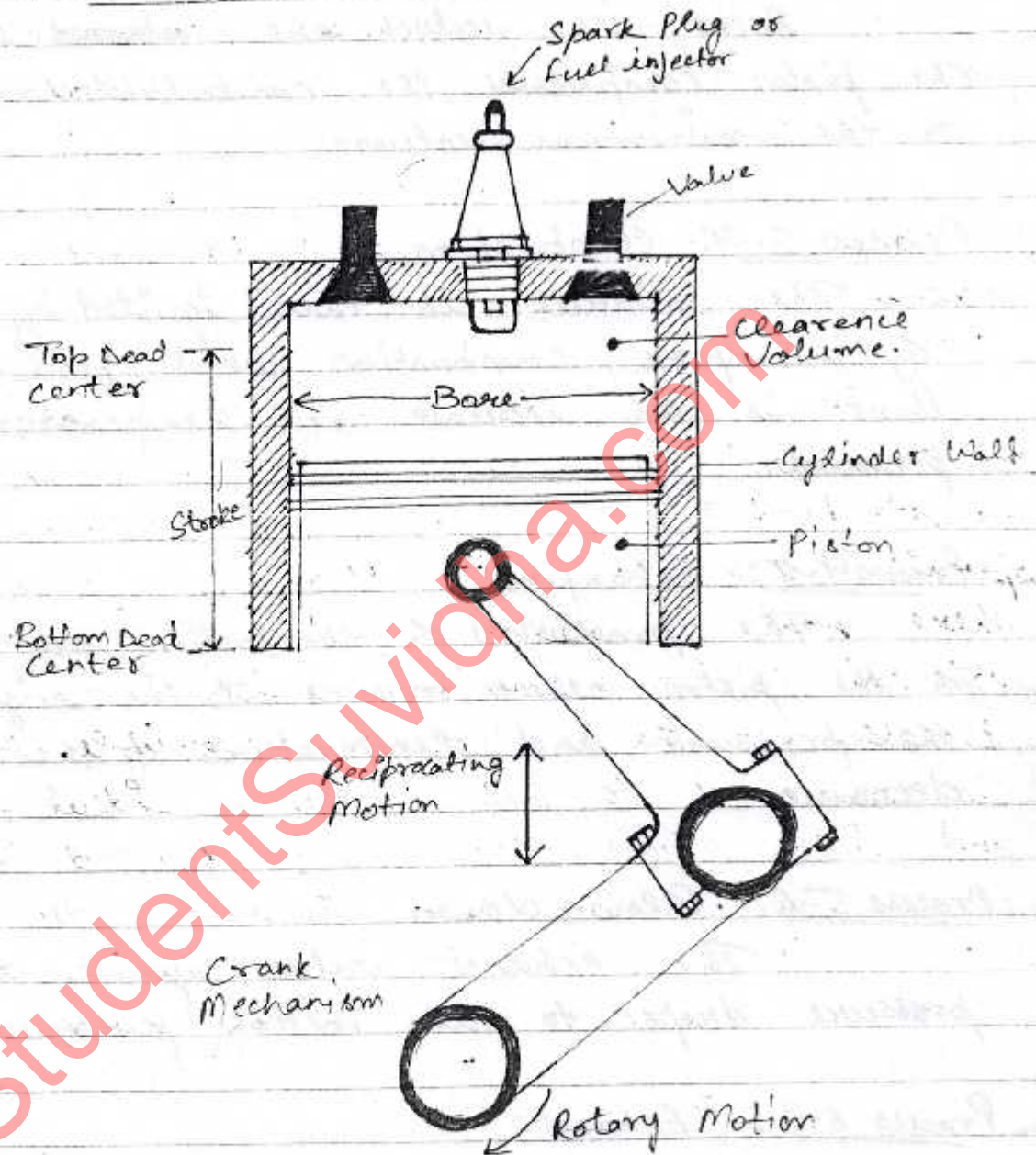
Process 5-6:- Blow down,

The exhaust valve opens, and the pressure drops to the initial pressure.

Process 6-1:- Exhaust,

With the exhaust valve open, the piston moves inwards to expel the combustion products from the cylinder at constant pressure.

→ AIR STANDARD CYCLES :-



Internal Combustion Engines (Fig. a) in which the combustion of fuel occurs in the engine cylinder itself are non-cyclic heat engines. The temperature due to the evolution of heat ~~is~~ because of the combustion of fuel inside the cylinder is so high that the cylinder is cooled by water circulation around it to avoid scald

deterioration. The working fluid, the fuel-air mixture, undergoes permanent chemical change due to combustion, and the products of combustion after doing work are thrown out of the engine, and a fresh charge is taken. So the working fluid does not undergo a complete thermodynamic cycle.

To simplify the analysis of I.C. engines, air-standard cycles are conceived. In an air standard cycle, a certain mass of air operates in a complete thermodynamic cycle, where heat is added and rejected with external heat reservoirs, and all the processes in the cycle are reversible. Air is assumed to behave as an ideal gas, and its specific heats are assumed to be constant. These air standard cycles are so conceived that they correspond to the operations of internal combustion engines.

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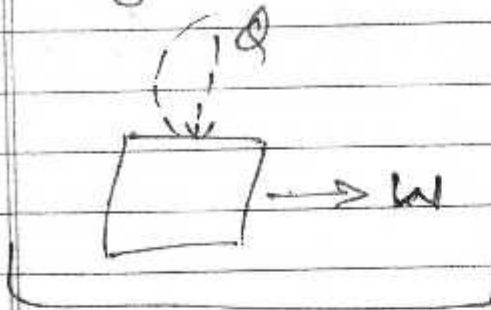
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Thermodynamics

(32) →

PMM I :-

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⇒ Second Law :-

(40)

⇒ Quality of Energy :-

(48)

Work / mechanical energy is high grade energy whereas heat / thermal energy is low grade energy.

(55)

100% conversion of high grade energy to low grade energy is possible whereas the converse is not true. due to thermal imbalance of environment with the system.

(49)

Two major things to be considered :-

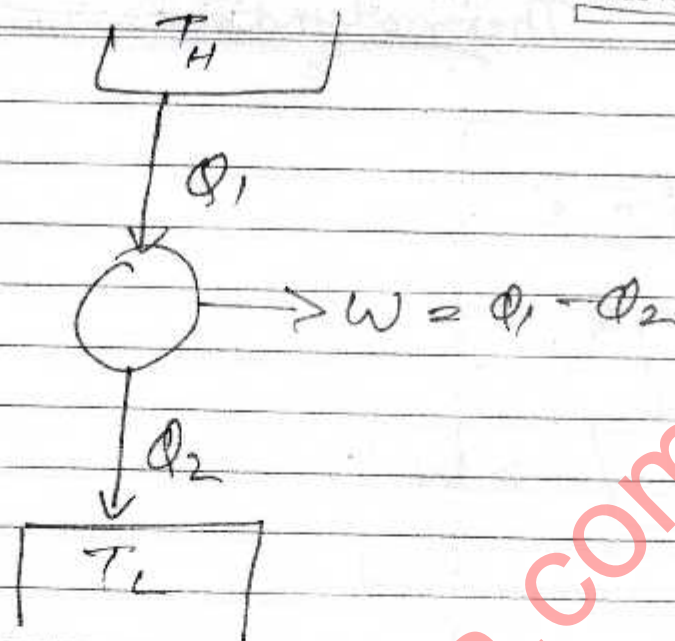
1) Kelvin Planck Statement :-

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It is impossible to construct a thermodynamic device which, while working on a thermodynamic cycle continuously produces work while interacting with a single reservoir. (No heat engine can be 100% efficient, as it has to throw some heat to another reservoir).

* Efficiency $\Rightarrow \frac{\text{Energy sought}}{\text{Energy that costs}} = \eta$

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

(76)

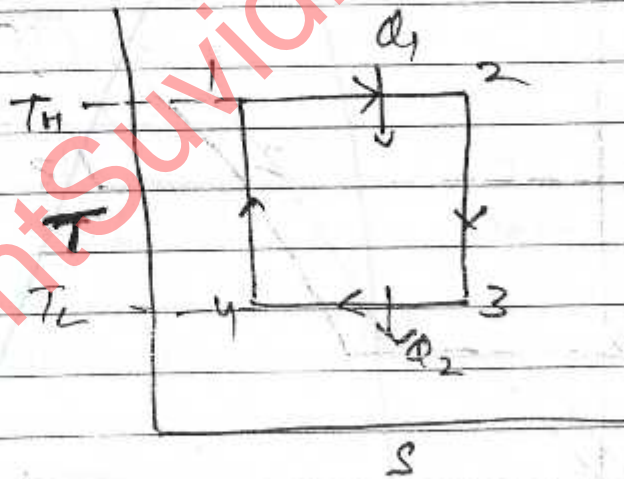
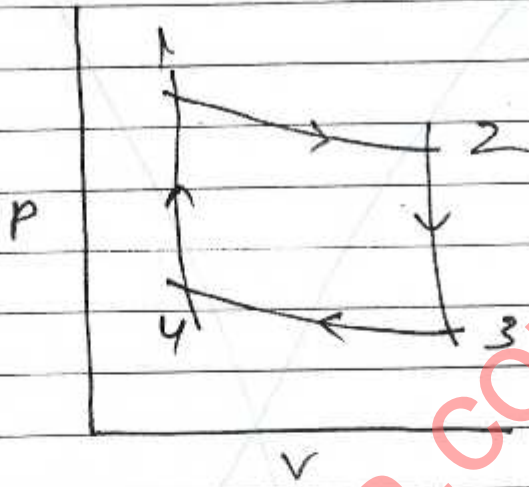
Carnot Cycle

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isothermal

)



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

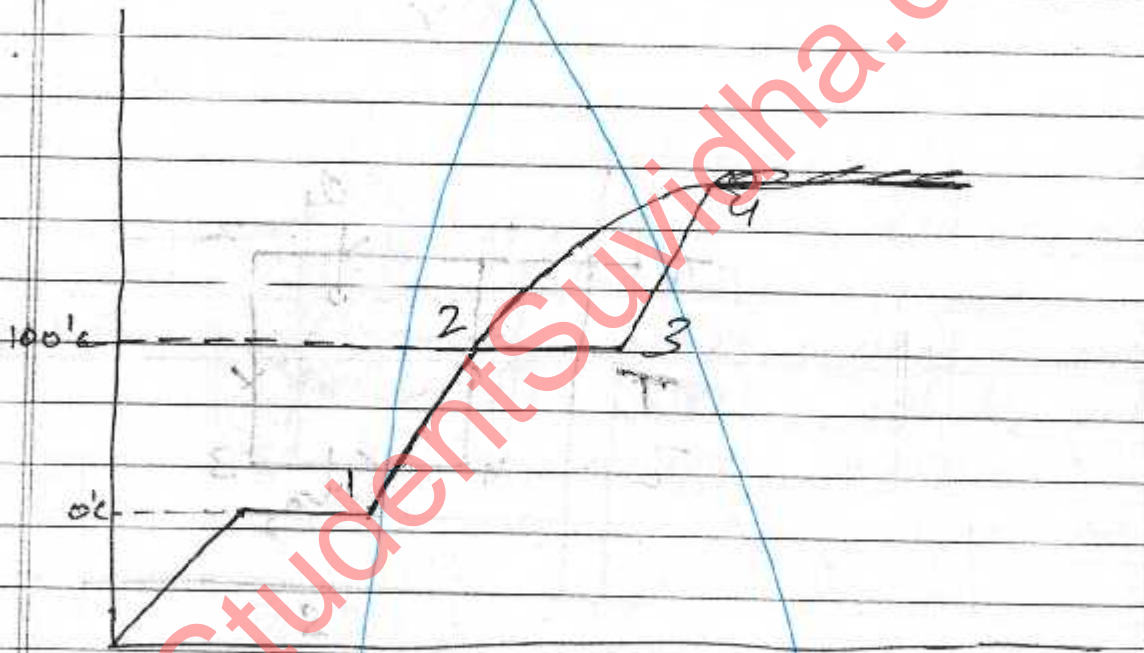
$$= \frac{Q_1 - Q_2}{Q_1}$$

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→ Kalidas is greater than any other dramatist.

→



77

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$$1Q_2 = 1W_2 + du$$

$$1Q_2 = 1W_2$$

(du = 0 in isothermal process)

$$\therefore 1Q_2 = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$2Q_3 = 2W_3 + du$$

$$2Q_3 = 0 \quad (\text{adiabatic process})$$

$$2W_3 = \left[\frac{P_2 V_2 - P_3 V_3}{\gamma - 1} \right]$$

$$\therefore 1W_2 = \int_{V_1}^{V_2} P dV$$

$$= C \int \frac{dV}{V^\gamma}$$

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

$$3Q_4 = 3W_4 + du$$

$$3Q_4 = 3W_4$$

$$= P_3 V_3 \ln \frac{V_4}{V_3}$$

$$q_1 = 0$$

$$w_1 = \frac{P_4 V_4 - P_1 V_1}{\gamma - 1}$$

$$(w_2 + w_3) - (w_4 + w_1)$$

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

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

$$= 1 - \frac{P_2 V_2 \ln \frac{V_3}{V_2}}{P_1 V_1 \ln \frac{V_2}{V_1}}$$

$$= 1 - \frac{R T_2 \ln \frac{V_3}{V_2}}{R T_1 \ln \frac{V_2}{V_1}} = 1 - \frac{T_2}{T_1}$$

$$T_2 V_2^{\gamma-1} = T_3 V_3^{\gamma-1} \quad (\text{As we know})$$

$$(TV^{\gamma} = C)$$

$$\frac{V_2}{V_3} = \frac{T_3}{T_2}$$

$$T_1 V_1^{\gamma} = T_4 V_4^{\gamma}$$

(99)

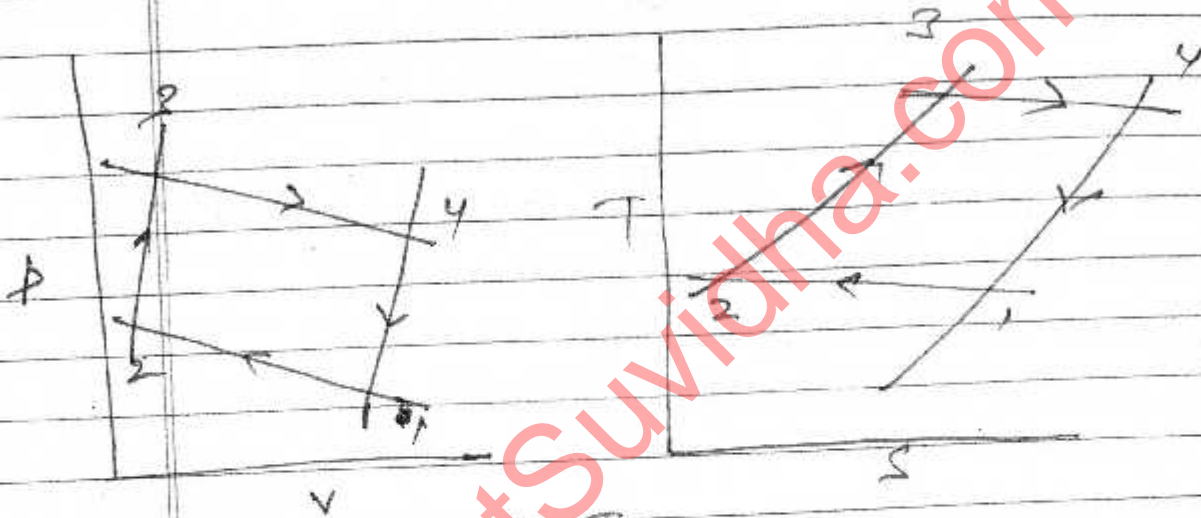
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$$\frac{V_1}{V_4} = \frac{T_4}{T_1} \quad 1/27$$

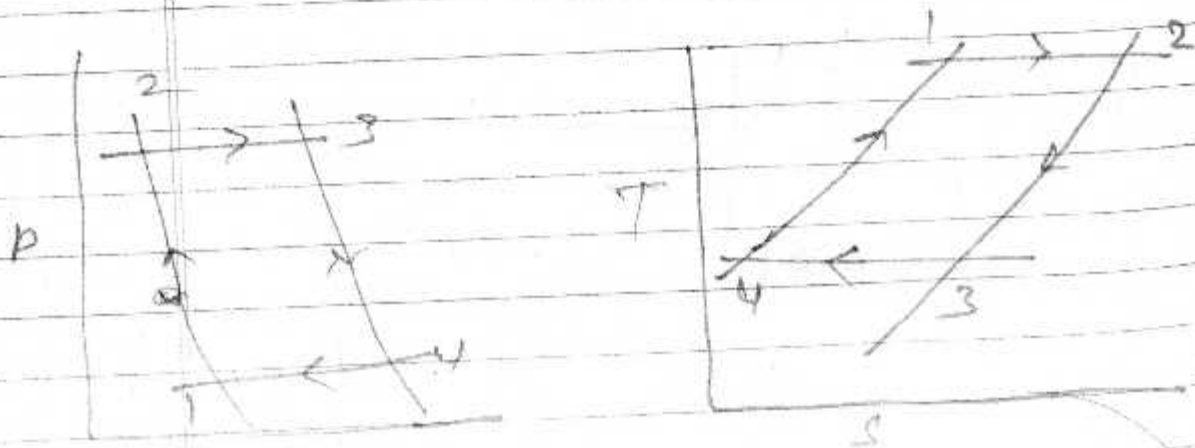
⇒ ~~Stirling~~

⇒ Stirling Cycle



$$\eta = 1 - \frac{T_L}{T_H}$$

Ericson Cycle :-



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Otto Cycle

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

HR

$$Q_2 = Q_1 = m C_v (T_4 - T_1)$$

HS

$$Q_1 = Q_2 = m C_v (T_3 - T_2)$$

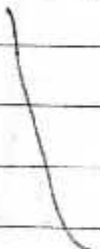
$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$= 1 - \frac{T_1}{T_2}$$

$$= 1 - \frac{1}{(V_1/V_2)^{\gamma-1}}$$

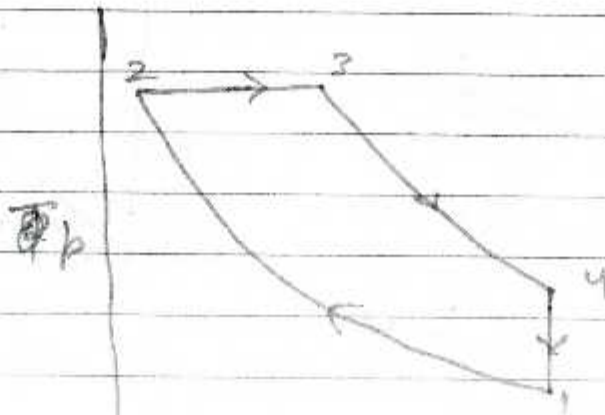
$$\eta = 1 - \frac{1}{(r_k)^{\gamma-1}}$$

← →



→

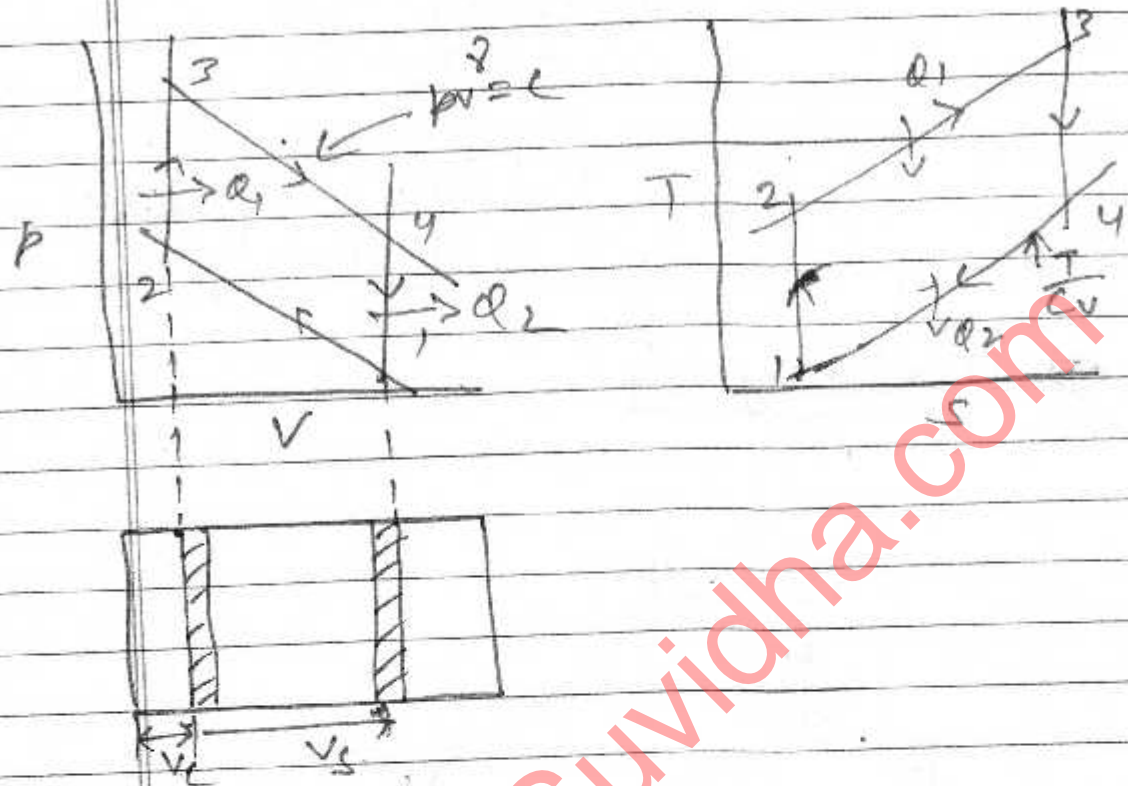
Diesel Cycle



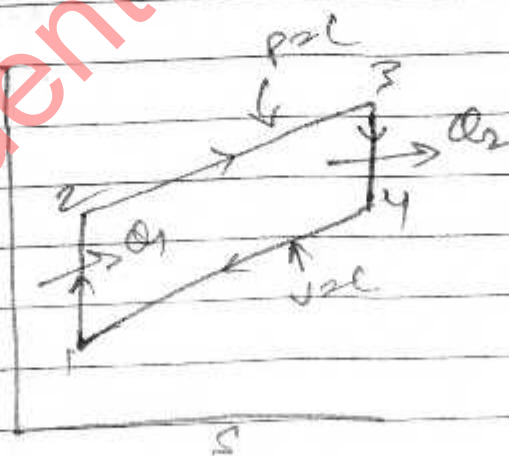
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← →



$$Q_1 = Q_2 = \dot{m} c_p (T_3 - T_2)$$

$$Q_2 = Q_1 = \dot{m} c_p (T_4 - T_1)$$

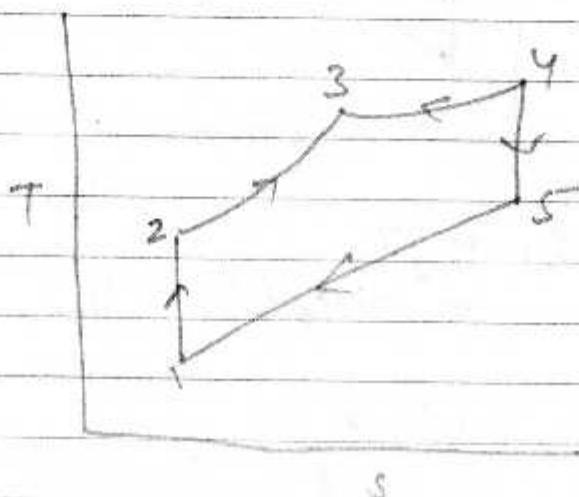
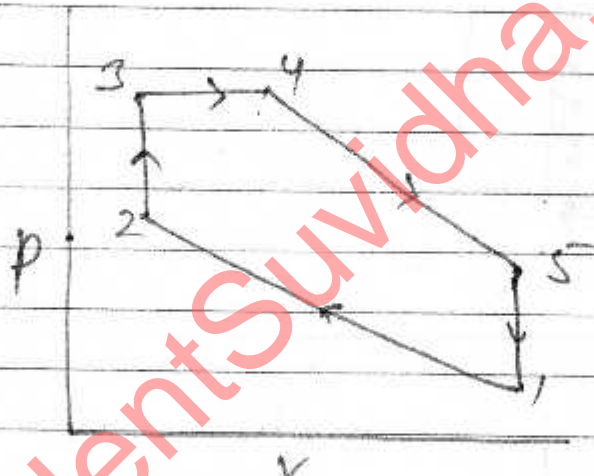
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$$= 1 - \frac{C_v (T_4 - T_1)}{C_p (T_3 - T_2)}$$

$$\eta = 1 - \frac{1}{\gamma} \left[\frac{T_4 - T_1}{T_3 - T_2} \right] \quad [\because \gamma = \frac{C_p}{C_v}]$$

⇒ Dual - Cycle



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

$$\eta = 1 - \frac{C_v(T_3 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

⇒

Q) An engine working on Otto cycle is supplied with air @ 0.1 MPa, The compression ratio is 8, heat supplied is 2100 KJ/kg. Calculate the max pressure & temp of cycle, the cycle efficiency.

For air,

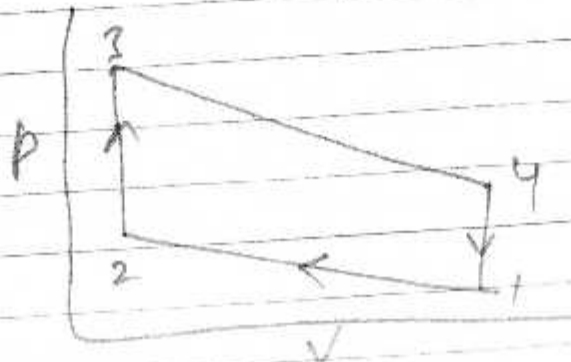
$$C_p = 1.005 \text{ KJ/kg}, Q_1 = 2100 \text{ KJ/kg}$$

$$C_v = 0.178 \text{ KJ/kg}, P_1 = 0.1 \text{ MPa}$$

$$r = 0.287 \text{ KJ/kg} = 0.1 \times 10^6 \frac{\text{N}}{\text{m}^2}$$

$$\frac{V_1}{V_2} = \frac{V_4}{V_3} = 8$$

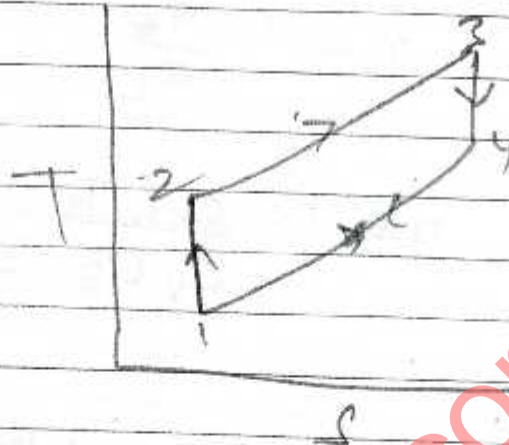
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$$T_1 = 35^\circ\text{C}$$

$$= 308\text{K}$$

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

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

$$P_2 = \frac{1.508 \times 10^6}{0.1 \times 10^6} [8]^{1.4}$$

$$P_2 = 1.873 \times 10^6 \frac{\text{N}}{\text{m}^2}$$

$$P_2 = 1.873 \times 10^6 \frac{\text{N}}{\text{m}^2}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_2 = \frac{P_2 V_2}{P_1 V_1} \times T_1$$

$$= \frac{1.873 \times 1 \times 308}{0.1 \times 8}$$



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THE IDEAL GAS

The ideal gas equation is very well known approximation in relating thermal properties for a state point, or during a process. However, not all gases are perfect, and even the same gas, may behave as an ideal gas under certain circumstances, then changes into non-ideal, or real, under different conditions.

Ideally, the behaviour of air is characterised by its mass, the volume it occupies, its temperature and the pressure condition in which it is kept. An ideal gas is governed by the perfect gas equation of state which relates the state pressure, volume & temperature of a fixed mass (m is constant) of a given gas (R is constant) as:

$$\frac{PV}{T} = mR$$

Where, P - Pressure (Pa)

V - Volume (m^3)

T - Absolute Temp. (K)

$$T(K) = 273 + t(^{\circ}C)$$

The equation of state can be written in the following forms, depending on what is needed to be calculated;

- 1) In terms of the pressure:-

$$P = \frac{mRT}{V}$$

- 2) In terms of the volume:-

$$V = \frac{mRT}{P}$$

Similarly, for

- 3) Mass $\Rightarrow m = \frac{PV}{RT}$

and for

- 4) Temperature $\rightarrow T = \frac{PV}{mR}$

- 5) Gas Constant $\rightarrow R = \frac{PV}{mT}$

- 6) Density (ρ) $\rightarrow \rho = \frac{m}{V} = \frac{P}{RT}$

be
needed

→ Alternative Gas Equation During a Change of State:

The equation of state can be used to determine the behaviour of the gas during a process, i.e. what happens to its temperature, volume and pressure if any one property is changed. This is defined by a simple expression relating the initial and final states such as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

this can be rewritten in terms of the final condition, hence the following equations are generated:

Final Pressure,

$$P_2 = P_1 \times \frac{T_2}{T_1} \times \frac{V_1}{V_2}$$

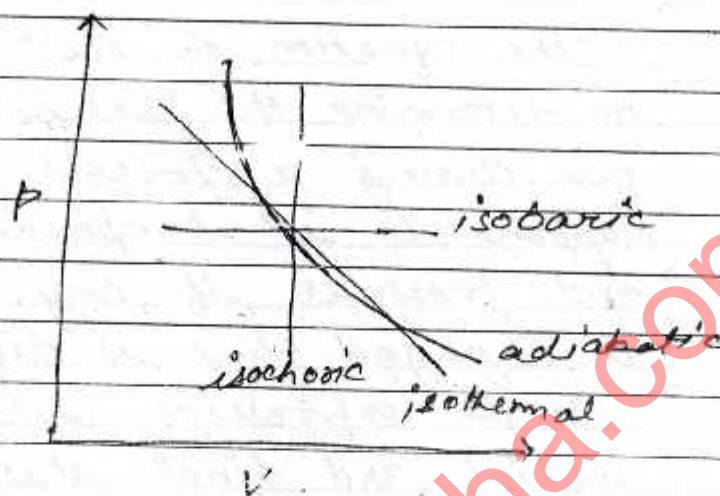
Final Temperature,

$$T_2 = T_1 \times \frac{P_2}{P_1} \times \frac{V_2}{V_1}$$

Final Volume,

$$V_2 = V_1 \times \frac{P_1}{P_2} \times \frac{T_2}{T_1}$$

→ Thermodynamic Processes For Gases



There are four distinct processes which may be undertaken by a gas :-

a) Constant volume process (isochoric process):-

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

b) Constant pressure process (isobaric process):-

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

c) Constant temp. process (isothermal process):-

$$P_1 V_1 = P_2 V_2$$



Gases +

d) Polytropic process:-

$$P_1 V_1^n = P_2 V_2^n$$

* Note:- When $\eta = \frac{C_p}{C_v}$, the process is known as adiabatic process.

tic

→ Compressibility of Gases

Compressibility factor, z , is a measure of deviation from the ideal gas.

$$z = \frac{P \cdot v}{R \cdot T}$$

cesses

+ a

tic process):-

where, v is the specific volume (m^3/kg)
* Note:- $z = 1$ for an ideal gas.

process):-

As z approaches 1 for a gas at given conditions, the behaviour of the gas approaches ideal gas behaviour. Although, different gases have very different specific properties at various conditions; all gases behave in a similar manner relative to their critical pressure, P_{cr} and critical temperature, T_{cr} .

process):-

Hence, the gas pressures and



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temperatures are normalized by the critical values to obtain the reduced pressure, P_r & temperature T_r defined as

$$P_r = \frac{P}{P_{cr}}$$

$$T_r = \frac{T}{T_{cr}}$$

⇒ Quality/Property of Pure Substance

A pure substance is one, which is homogenous and chemically stable. Thus it can be a single substance which is present in more than one phase, for example liquid water & water vapour contained in a boiler in the absence of any air or dissolved gases.

* Phase → is the state of the substance such as solid, liquid or gas.

* Mixed Phase → It is possible that phases maybe mixed, ex; ice + water, water + vapour etc.

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by the
use T_R .

* Quantity of a Mixed Phase or Dryness Fraction (x);

The dryness fraction is defined as the ratio of the mass of pure vapour present to the total mass of the mixture (liquid and vapour; say 0.9 dry for example). The quality of the mixture may be defined as the percentage dryness of the mixture (i.e., 90% dry).

are +
re, which
stable,
substance
an one
re of
boiler
or

* Saturated State:- A saturated liquid is a vapour whose dryness fraction is equal to zero. A saturated vapour has a quality of 100% or a dryness fraction of one.

* Superheated Vapour:- A gas is described as superheated when its temperature at a given pressure is greater than the saturated temperature at that pressure, i.e., the gas has been heated beyond its saturation temperature.

liquid

* Degree of Superheat:- The difference between the actual temperature of a given vapour and the saturation temperature of the vapour at a given pressure.

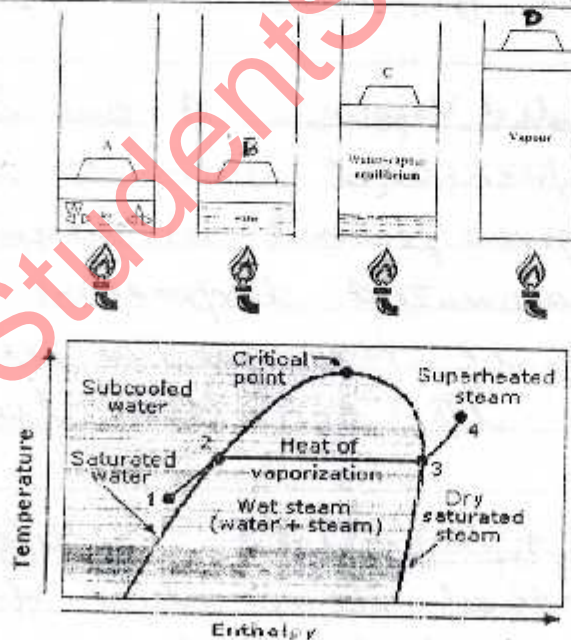
that
+ water,

* Degree of Subcool:- The difference between the saturation temperature and the actual temperature of the liquid at a given pressure.

* Triple Point:- A state point in which all solid, liquid and vapour phases coexist in equilibrium.

* Critical Point:- A state point at which transitions between liquid and vapour phases are not clear.

⇒ The State Diagram - For Steam



Processes 1-2, 2-3 and 3-4 represents a typical constant pressure heating of water which initially

between
and the
liquid.

which

which

heated to its boiling point, (1-2),
upon continued heat input it starts
to evaporate at point 2, it is
~~completely~~ completely liquid, then gradually
some of the water becomes vapour
till it reaches point 3, where all
the water has evaporated, further
heating will make the water vapour
superheated (process 3-4).

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4
pressure
ally

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