THERMAL ENGG & (BASIC MECHANICAL ENGINEERING)
MECH-ELE
(Electrical Engg) (MEC-101)
(Civil) 1.

UNIT-1 (Thermodynamics) & for (Thermal unit 2)

Introduction:-

The field of science dealing with energy in the form of heat and work and their conversion into each other and the effect of energy transfer on the properties of system is called Thermodynamics.

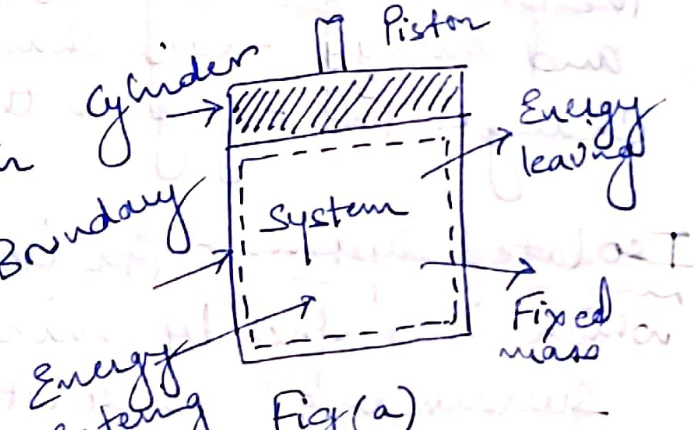
System & Surroundings

A thermodynamics system is defined as a region in space or a quantity of matter upon which attention is focussed for the study of work and heat transfer and conversion. Every thing outside the system which has direct bearing on its behaviour is known as surrounding.

The different type of system are as follow

1) closed system :-

An example of a closed system is piston in a cylinder as shown in Fig. The mass of the closed system remain constant and only energy can flow through the boundary in or out ~~energy can~~ flow of a closed system. The volume of a closed system need not be constant and it change due to the movement of the piston in the cylinder. Work transfer



Fig(a)

b/w system and surrounding takes place due to the movement of the boundary of the system considered. Closed system concept is very often used in thermodynamics analysis.

Open system :-

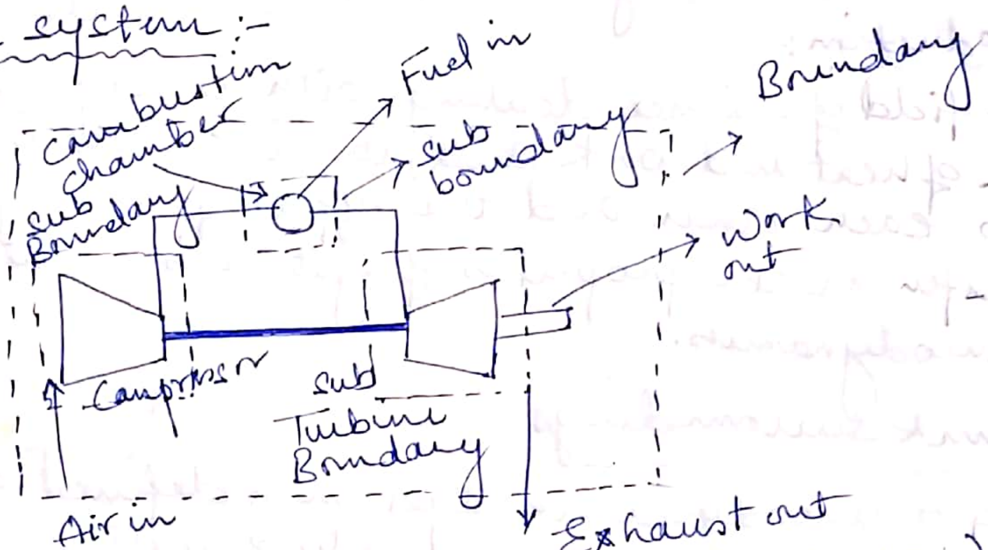


Fig (b) Gas turbine power plant (Open system)

Mass Transfer also take place through the boundary in addition to the work and heat transfer in case of open system. The boundary of the open system is known as Control Volume. The boundary during the transfer of mass and energy may change or may not change. The Fig gives the example of it.

Isolated System:- An isolated system is one which is completely uninfluenced by the surrounding. An isolated system cannot interchange either mass or energy with the surroundings.

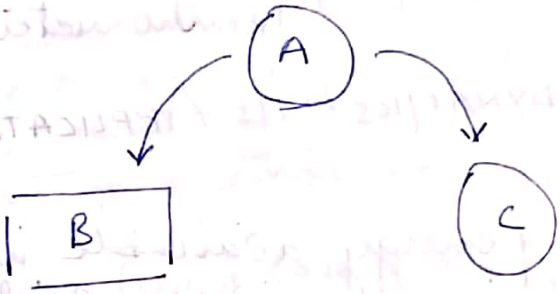
Homogenous & Heterogeneous System

If the matter within the system exist in a single phase like air, steam or liquid, the system is known as homogenous system.

Air in the cylinder during the compression strokes of diesel engine can be considered as homogeneous system.

ZEROTH LAW :-

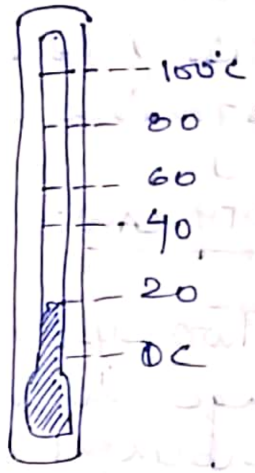
"Two system are equal in temperature if no change in any property occur when they are brought into contact"



If we apply the concept of temperature equality to an experiment involving these system A, B & C as shown in Fig an experimental law regarding temp can be established.
The zeroth law of thermodynamics states that when 2 bodies have equal equality of temp with third body, they in turn have equality of temperature with each other.

Celsius Temperature Scale

Temperature ~~are measured through a change~~ scale is defined by assigning number to the point (0), to steam point (100) and to the equally spaced marks (100 marks) b/w those points.
If the third body (D), the mercury thermometer graduated in this way, is brought into the contact with system (D) where upon the mercury rises to the subdivision marked (50) then we can say that system D has a temp of 50 celsius and denoted by 50°C



Mercury Thermometer

FIRST LAW OF THERMODYNAMICS & ITS APPLICATION

INTRODUCTION

Heat is one form of energy available in very large quantities in the universe which can be transformed into the useful form of energy work. Heat interaction b/w system and surrounding is essential for transforming heat into work.

TOTAL INTERNAL ENERGY

Energy that remain within the boundary of a system will be called its total internal energy. The energy is associated with the matter in the form of potential energy, kinetic energy as well as magnetic, electrical, chemical and many other form of energy. In absence of other form of energy except potential, kinetic and internal the energy possessed by the mass is known as total energy

$$e_t = u + PE + KE$$

where e_t is known as total internal energy

ENTHALPY

The amount of heat contain in the body is called enthalpy. It is denoted by h. u is internal energy and p and v_s are the pressure and specific volume of the fluid taking part in the heat and work reaction

$$h = u + Pv_s$$

LAW OF CONSERVATION OF MASS

This law stats that mass cannot be created or destroyed in the absence of nuclear reaction but may be converted ~~for~~ from one from to another from

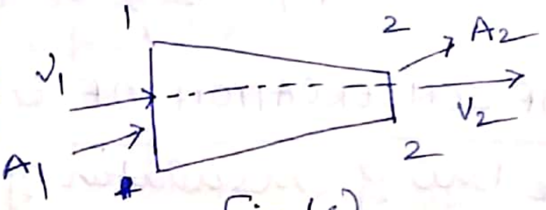


Fig (c)

Consider a fluid passing through a system as shown in Fig (c) and taking element length of the pipe, the mass flow through this element area $\delta m = (A\delta x)\rho$ where A is cross-sectional area and ρ is density of the flowing fluid.

$$\therefore \frac{\delta m}{\delta t} = A \cdot \left(\frac{\delta x}{\delta t}\right)\rho$$

If $\delta t \to 0$

the mass m flowing through the pipe per unit time is given by

$$m = A.v.\rho \quad \text{where} \left(\frac{\delta x}{\delta t}\right)_{\delta t \to 0} = v \text{ (the velocity of the fluid)}$$

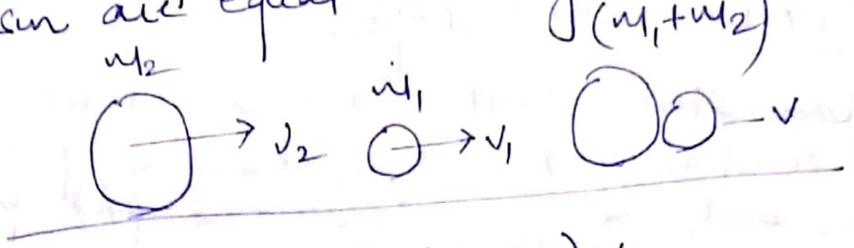
For steady state condition

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

This is known as one-dimensional steady flow continuity equation

LAW OF CONSERVATION OF MOMENTUM

If no external force act on a system, the linear momentum is conserved both in magnitude and direction. Conservation of momentum occurs whether the collision is elastic or not. A familiar example is the collision of 2 sphere. The sum of the momenta of the 2 sphere before & after collision are equal in magnitude & direction



$$m_1v_1 + m_2v_2 = (m_1+m_2)V$$

LAW OF CONSERVATION OF ENERGY

The law of conservation of energy states that energy can neither be created nor destroyed whenever there is a change in the state of a system. there is only transformation of one form of energy into another

FIRST LAW OF THERMODYNAMICS

The law state that If a system execute a cycle transferring work and heat through its boundary, then the net work transfer is equivalent to the heat transfer

or $\oint dW = \oint dQ$

The first law of thermodynamics cannot be proved mathematically but experimental evidence have repeatedly confirmed its validity.

Application of First law to a process

When a system execute a process, the change in stored energy of the system is numerically equal to the net heat interactions minus the net work interaction during the process

$$E_2 - E_1 = Q - W$$

$$\Delta E = Q - W$$

$$\text{or } \Delta E = (E_2 - E_1) = \int_1^2 d(Q - W)$$

where E represent the total energy.

APPLICATION OF FIRST LAW TO NON FLOW OR CLOSED SYSTEM

(a) FREE EXPANSION

The state of the gas is fully defined by pressure, volume and temperature. The internal energy u can be expressed as a function of any 2 properties of the state of gas

$$u = f_1(T, v)$$

$$u = f_2(T, P)$$

$$u = f_3(P, v)$$

The total differential of the internal energy can be written as

$$du = \left(\frac{\delta u}{\delta T}\right)_v dT + \left(\frac{\delta u}{\delta v}\right)_T dv$$

$$du = \left(\frac{\delta u}{\delta T}\right)_p \cdot dT + \left(\frac{\delta u}{\delta p}\right)_T \cdot dp$$

$$du = \left(\frac{\delta u}{\delta p}\right)_V \cdot dp + \left(\frac{\delta u}{\delta v}\right)_p \cdot dv$$

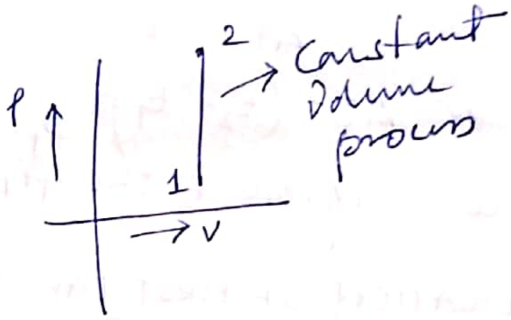
The internal energy of an ideal gas in which there are no forces of molecular interaction does not depend on volume or pressure and so

$$\left(\frac{\delta u}{\delta v}\right)_T = 0 \quad \& \quad \left(\frac{\delta u}{\delta p}\right)_T = 0$$

$$\left(\frac{\delta u}{\delta T}\right) = \left(\frac{\delta u}{\delta T}\right)_v = \left(\frac{\delta u}{\delta T}\right)_p$$

(b) Reversible Constant Volume Process

The system and the states before and after heat addition at constant volume are shown



Considering the mass of the system as unity and applying the first law to the process

$$Q = W + (u_2 - u_1)$$

The workdone $W = \int_1^2 p\,dv = 0$ & $dv = 0$

$$\therefore Q = (u_2 - u_1) = C_v (T_2 - T_1)$$

where C_v is known as specific heat at constant volume

$C_v = \left(\frac{\Delta u}{dT}\right)$ change in internal energy per degree change in temp per kg mass

(c) Reversible constant Pressure Process

The system and the states before and after heat addition

Considering the mass of the system unity and applying the first law to the process

$$Q = W + (U_2 - U_1) \quad ①$$

The workdone

$$W = \int_1^2 P\,dV = P(V_2 - V_1)$$

$$Q = \frac{P(V_2 - V_1)}{J_c} + (U_2 - U_1)$$

where J_c is conversation factor which is unity in S.I system

$$Q = (V_2 + PV_2) - (U_1 + PV_1) = h_2 - h_1 = C_p(T_2 - T_1)$$

where h = is the enthalpy and C_p is known as the specific heat at constant pressure

$C_p = \frac{\Delta h}{dt}$, Change in enthalpy per degree change in temp per kg mass

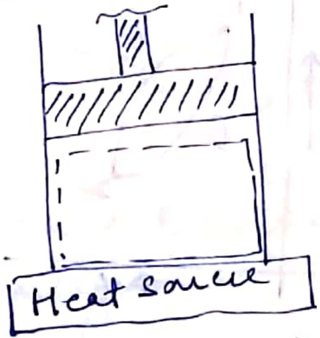
Also $Q = C_p(T_2 - T_1)$

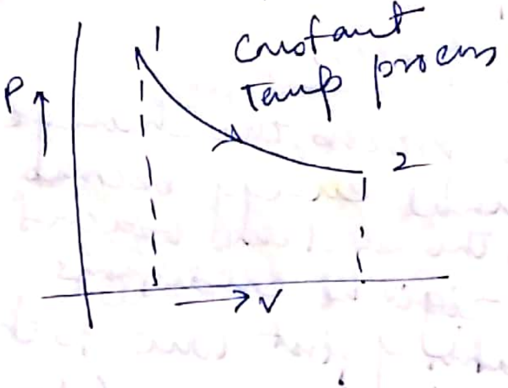
$$= (P_2V_2 - P_1V_1) + (U_2 - U_1) = R(T_2 - T_1) + C_v(T_2 - T_1)$$

$\therefore C_p = R + C_v$

(d) Reversible Isothermal Process

The system and the states before and after heat addition at constant temp





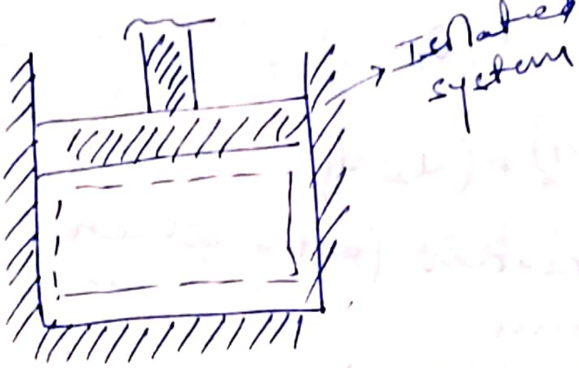
Considering the mass of the system unity and applying the first law to the process

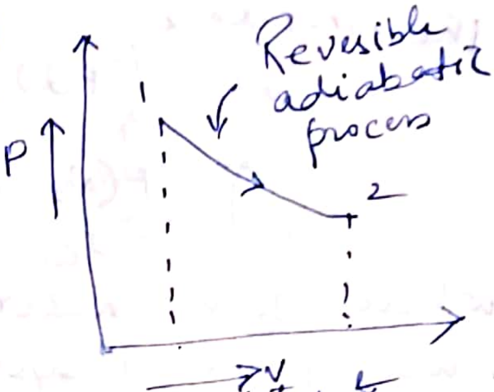
$$Q = w + (u_2 - u_1) = w + C_v(T_2 - T_1)$$

$$= w + 0 \text{ as } T_2 = T_1$$

$$= \int_1^2 p\,dv.$$

(e) Reversible Adiabatic Process





Considering the mass of the system unity & applying the first law to the process

$$Q = w + u_2 - u_1$$

$$0 = w + u_2 - u_1 \quad \text{as } Q = 0$$

$$\therefore \; w = u_1 - u_2 = C_v(T_1 - T_2)$$

The above equation that the system develops work as the expense of its internal energy

(f) Irreversible Process

The work done in the previous process is given by $w = \int_1^2 p\,dv$ but this cannot be applied to processes such as free expansion and when paddle work is done on the system

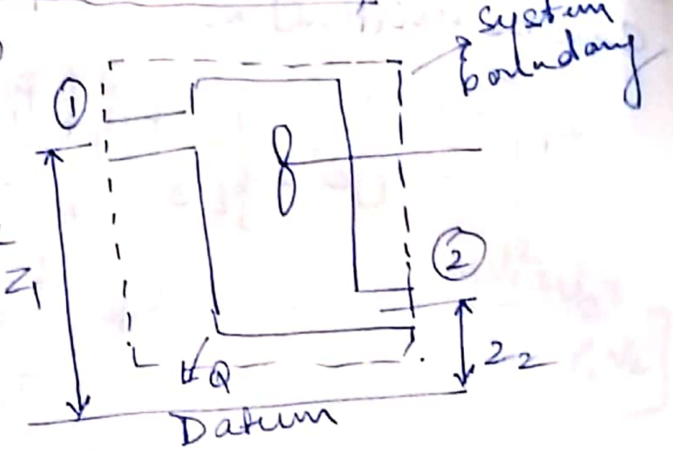
(g) Cyclic Process

A cyclic process, the change in internal energy becomes zero as the system reaches to its original conditions

Application of first law to this cyclic process $\oint dQ = \oint dw$

APPLICATION OF FIRST LAW TO STEADY FLOW

Consider a steady flow system as shown in the following fig. The following assumption are made in the system analysis



(1) The mass flow through the system remain constant

(2) There is no change in chemical composition of the fluid or there is no chemical reaction

(3) The state of fluid at any point remain constant with time

(4) Fluid is uniform in composition

(5) The potential, kinetic, internal and flow energies are only considered in the analysis. Other forms of energy (electrical, chemical, magnetic etc) are not considered in most of the thermodynamic system discussed.

(6) The only interaction b/w system and surrounding are work and heat.

It is considered that the working fluid enters in the system at condition 1 and leaves the system at condition ②. Therefore the energy and exist are subscripted by ① & ②

As per the law of conservation of energy.

$$E_1 \pm W \pm Q = E_2$$

where E represent the sum of all the energies associated with the fluid

For thermodynamic system, the above equation can be written as

$$m\left[\frac{Z_1}{J_c}\cdot\frac{g}{g_c}+\frac{V_1^2}{2g_cJ_c}+u_1+\frac{P_1v_{s_1}}{J_c}\right]\pm w\pm Q= m\left[\frac{Z_2}{J_c}\cdot\frac{g}{g_c}+\frac{V_2^2}{2g_cJ_c}+u_2+\frac{P_2v_{s_2}}{J_c}\right]. \quad -①$$

where Z & V are elevation and velocity in metre/sec, u is internal energy in J/Kg resp. W & Q are work and heat interaction b/w the system & surrounding.

g = acceleration due to gravity (m/s^2)

g_c = force unit conversion constant ($1\,Kg\text{-}m/Ns^2$)

J_c = Joule constant to convert work unit into heat unit ($J_c = 1\,Nm/J$)

(a) The term $\frac{Z}{J_c}\frac{g}{g_c}$ is the potential energy/unit mass is Joule/Kg where Z is in metre

(b) The term $\frac{1}{2}\frac{V^2}{g_cJ_c}$ is the kinetic energy per unit mass in Joule/Kg where V is in (m/s)

(c) The term u is the internal energy per unit mass in Joule/Kg.

(d) The term $\frac{PV_s}{J}$ is the flow work per unit mass in Joule/Kg when P is N/m^2 and V_s is specific volume in m^3/Kg

Now substituting the value of $J_c=1$ and $g_c=1$ in the above equation

$$m\left[Z_1g+\frac{V_1^2}{2}+u_1+P_1v_{s_1}\right]\pm w\pm Q=m\left[Z_2g+\frac{V_2^2}{2}+u_2+P_2v_{s_2}\right]$$

By definition $h=u+\frac{Pv_s}{J_c}=u+Pv_s$ as $J_s=1$

Substituting this value in the above equation,

$$m\left[z_1g+\frac{V_1^2}{2}+h_1\right]\pm W\pm Q=m\left[z_2g+\frac{V_2^2}{2}+h_2\right]$$

The above 2 equation can also be written as:

$$\left[mz_1g+\frac{mV_1^2}{2}+U_1+P_1V_1\right]\pm W\pm Q=\left[mz_2g+\frac{mV_1^2}{2}+U_2+P_2V_2\right]$$

where $U_1=mu_1$ & $U_2=mu_2$
$V_1=mv_{s_1}$ and $V_2=mv_{s_2}$

$$\boxed{\left[mz_1g+\frac{mV_1^2}{2}+H_1\right]\pm W\pm Q=\left[mz_2g+\frac{mV_2^2}{2}+H_2\right]}$$

where $H_1=mh_1$ & $H_2=mh_2$.

SECOND LAW OF THERMODYNAMICS & CONCEPT OF ENTROPY

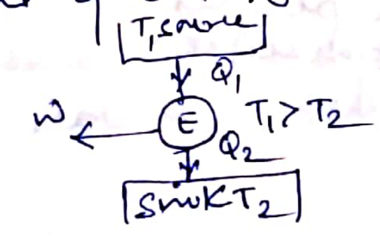
STATEMENTS OF SECOND LAW OF THERMODYNAMICS

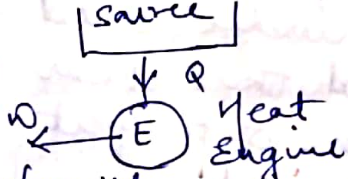
1) Kelvin-Plank statement

The Kelvin-Plank statement of the second law of thermodynamics states that "no system whose working fluid undergoes a cycle can receive heat from a single source" and produce work without rejecting heat to a lower Temp sink

OR

It is impossible to construct an engine working in a cyclic process whose sole effect is the ~~causes~~ conversion of all the heat energy supplied to it by a source into an equivalent amount of work.





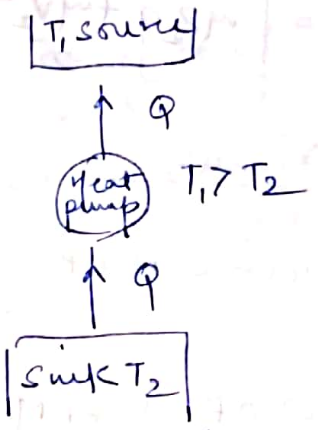
Impossible heat engine as per Kelvin + Planck statement

2) Clausius statement:

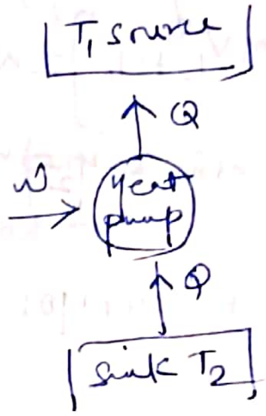
It state that "It is impossible to construct a device working in a cyclic process whose sole effect is ~~that~~ the transfer of energy in the form of heat from a body at a lower temp" (sink) to a body at a higher temp (source)

OR

It is impossible for energy in the form of heat to flow from a body at a lower temp to a body at higher temp without the aid of external work.



impossible system



possible system

CARNOT CYCLE

The carnot cycle consist of four reversible processes 2 frictionless isothermal and 2 frictionless adiabatics.

The following assumptions are made in the operation of carnot cycle.

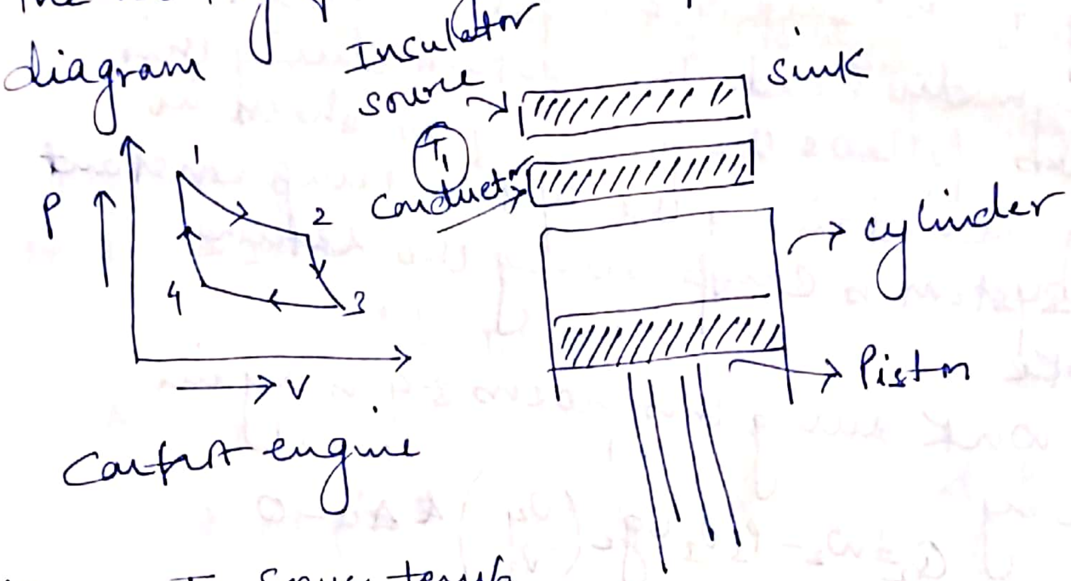
(1) The piston moving in a cylinder does not encounter any friction during motion

(2) The wall of piston and cylinder are considered as perfect heat insulators.

(3) The cylinder head of the cylinder is so arranged that it can be a perfect heat conductor or perfect heat insulator as required.

(4) The transfer of heat does not ~~a~~ affect the temperatur of the source or sink.

The working of the cycle is represented on P-V diagram



Carnot engine

(1) T_1 = Source temp
T_2 = Sink temp

The workdone during the process 1-2 as per the first law of energy equation is given by

$$Q_1 = W_1 = P_1 V_1 \log_e \left(\frac{V_2}{V_1}\right)$$ as $\Delta U = 0$ because the process is isothermal

$$= RT_1 \log_e \left(\frac{V_2}{V_1}\right)$$

This is the workdone by the system per kg of the working fluid

(2) During the process 2-3, the heat source is removed and cylinder head is perfectly non conducting, the gas expand reversibly and adiabatically $(Q=0)$ till its temp fall to T_2

Applying the First law of Thermodynamics to this process

$$Q = W + (U_2 - U_1)$$

$$\therefore W = (U_1 - U_2) = \Delta U$$ (decrease in internal energy) as $Q=0$

Workdone by the system at the expense or decrease in internal system using the characteristics gas/equation and considering unit mass of the system, we can write the above equation as

$$W = RT_1 \log_e\left(\frac{V_2}{V_1}\right) - RT_2 \log_e\left(\frac{V_3}{V_4}\right)$$ as $T_3 = T_2$ ∴

Applying the adiabatic law to the state point 2 & 3 and 4 and 1 we can write

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

& $$T_2 (V_4)^{\gamma-1} = T_1 (V_1)^{\gamma-1}$$

As temp at point 1 & 2 is T_1 and temp at the point 3 & 4 is T_2

from ~~eq~~ above equation

$$\frac{T_1}{T_2} = \left(\frac{V_3}{V_2}\right)^{\gamma-1} \quad \& \quad \frac{T_1}{T_2} = \left(\frac{V_4}{V_1}\right)^{\gamma-1}$$

Comparing the above 2 equation we can write

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

substituting the value for equation

$$W = R\left[T_1 \log_e\left(\frac{V_2}{V_1}\right) - T_2 \log_e\left(\frac{V_2}{V_1}\right)\right]$$

$$= R \log_e\left(\frac{V_2}{V_1}\right)(T_1 - T_2)$$

The efficiency of the Carnot cycle is given by

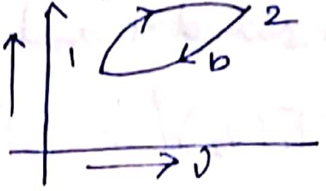
$$\eta_c = \frac{\text{Net Output}}{\text{Input}} = \frac{W}{Q_1}$$

sub the value of W and Q_1 we get

$$\eta_c = \frac{R \cancel{\log_e\left(\frac{V_2}{V_1}\right)}(T_1 - T_2)}{RT_1 \cancel{\log_e\left(\frac{V_2}{V_1}\right)}} = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

ENTROPY:

To measure the quality of the energy or to measure the irreversibility of a process. Clausius introduced a mathematical function which is named as ENTROPY.



Entropy is a consequence of the second law of thermodynamics and provide a method based on calculation, of explaining why certain energy transformation are impossible and of identifying the direction of any spontaneous process.

Consider a cycle shown in Fig. which is made of 2 reversible process following the path a & b. The reversible cycle is 1-a-2-b-1

As we have proved for a reversible cycle

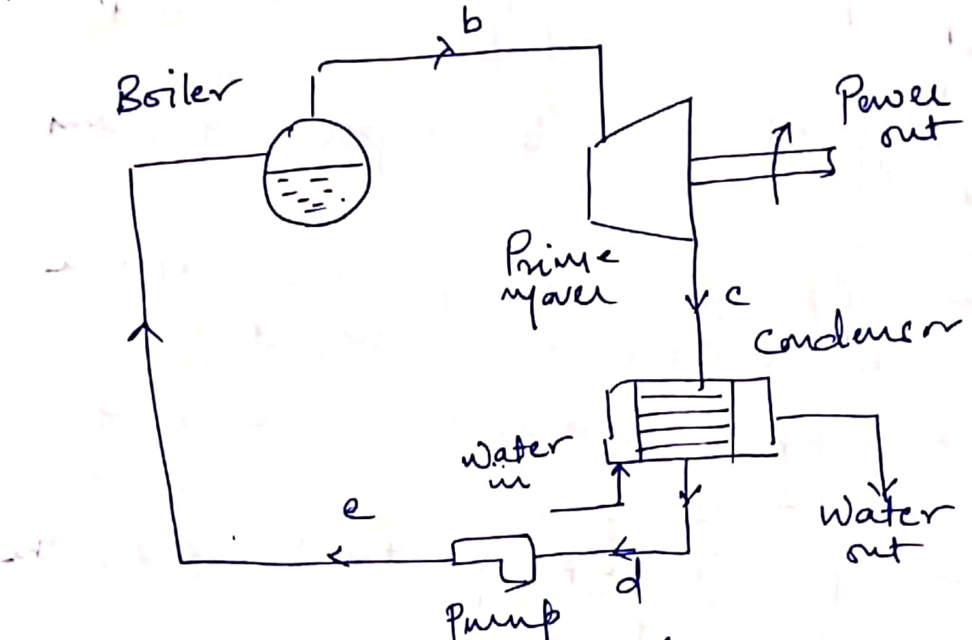
$$\oint_R \left(\frac{dQ}{T}\right)=0 \quad \therefore \int_{2(a)}^{2}\left(\frac{dQ}{T}\right)+\int_{2(b)}^{1}\left(\frac{dQ}{T}\right)=0$$

$$\therefore \int_{1(a)}^{2}\left(\frac{dQ}{T}\right)=-\int_{2(b)}^{1}\left(\frac{dQ}{T}\right)=\int_{1(b)}^{2}\left(\frac{dQ}{T}\right)$$

This indicate that no restriction is imposed on the path a and b except that they must be reversible. The expression $\int\left(\frac{dQ}{T}\right)$ is independent of the path followed. represent the property. This property is called "entropy" and denoted by s and defined by

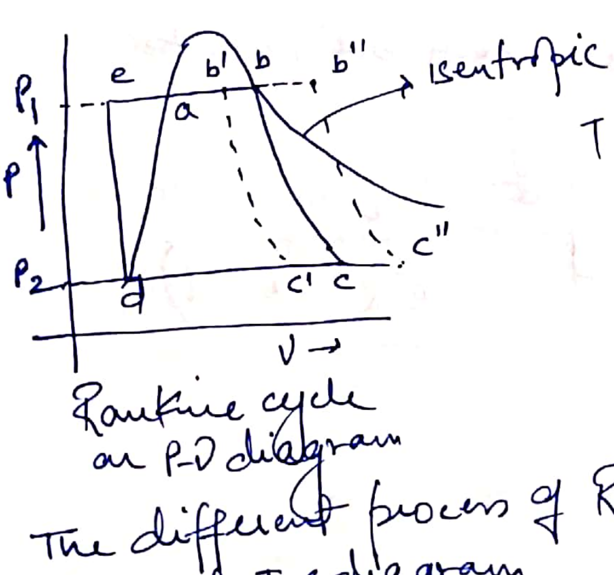
$$\boxed{ds=\left(\frac{dQ}{T}\right)_R \text{ or } s_2-s_1=\int_{1(R)}^{2}\left(\frac{dQ}{T}\right)}$$

Rankine cycle

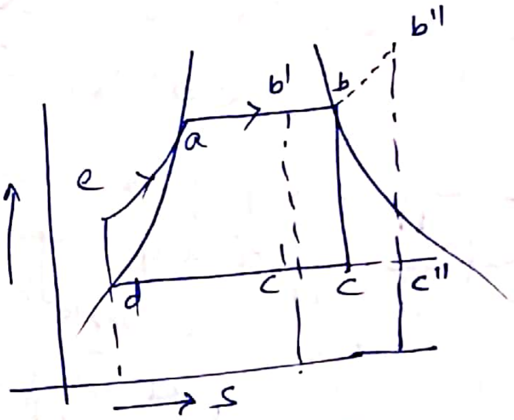


The arrangement of component in a steam power plant woking as Rakine cycle

The line diagram of the compoment of the steam power plant woking on Rankine cycle is shaon in Fig while the Rankie cycle on P.V and T-S diagram is



Rankine cycle on P-V diagram



Rankine cycle on T-S diagram

The different process of Rankine shaon is P-V and T-S diagram

let h_b = specific ~~eta~~ enthalpy steam at point 'b'

h_c = specific enthalpy of steam at point 'c'

v_f = specific volume of water at point d are

as the change in specific volume during this process is small.

h_{fe} = specific enthalpy of water at point 'e'
h_{fa} = specific enthalpy of water at point 'a'
h_{fd} = specific enthalpy of water at point 'd'

The heat supplied by the boiler per kg of steam generated

$= h_b - h_{fe}$

$= h_b - (h_{fd} + w_p)$ where w_p is the workdone by the pump per kg of water pumped

Workdone per kg of steam in the prime mover

$= h_b - h_c$

Workdone by pump per kg of water supplied to the boiler is given by

$w_p = v_w(P_1 - P_2)$ KJ/Kg of water

$= v_w(P_1 - P_2)10^{-3}$ KJ/Kg, where P_1 & P_2 are in N/m^2

$= 100 v_w(P_1 - P_2)$ KJ where P_1 & P_2 are in bars

and v_w is the specific volume of saturated water at pressure P_2

∴ Net work available per kg of water

$= (h_b - h_c) - v_w(P_1 - P_2) \times 100 = (h_b - h_c) - w_p$

The efficiency of the cycle which is known as Rankine efficiency is given by

$$\boxed{\therefore \eta_r = \frac{\text{Net work output}}{\text{Heat supplied}} = \frac{(h_b - h_c) - w_p}{h_b - (h_{wd} + w_p)}}$$