

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 thermodynamic 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 follows

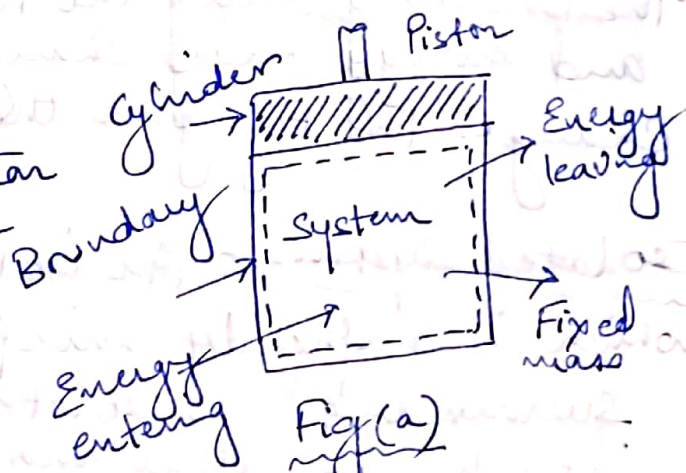
1) closed system :-

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



flow system and surrounding, takes place due to the movement of the boundary of the system considered. Closed system concept is very often used in thermodynamic analysis!

Open system :-

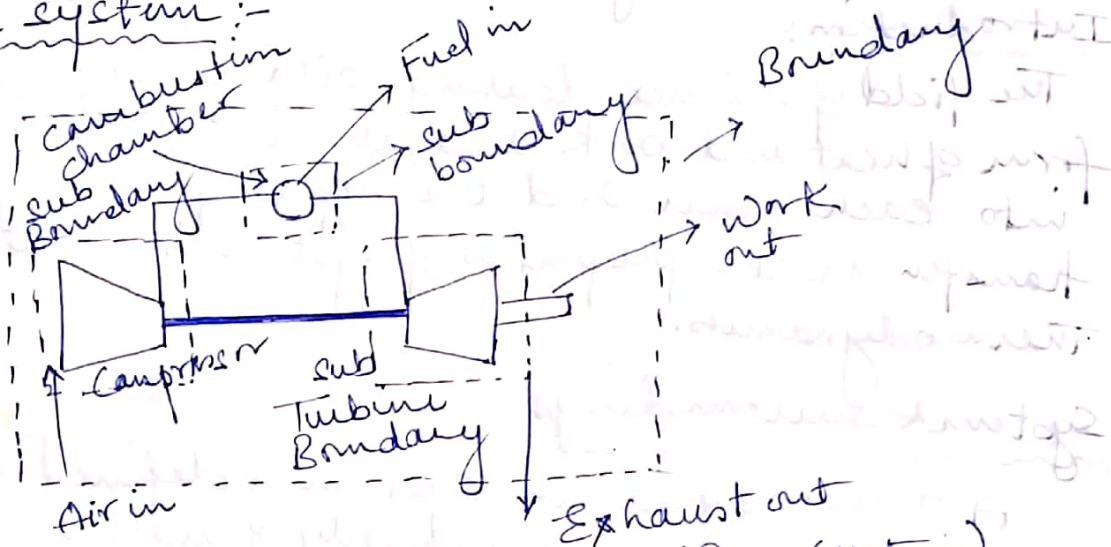


Fig (b) Gas turbine power plant (Open system)

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 give 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.

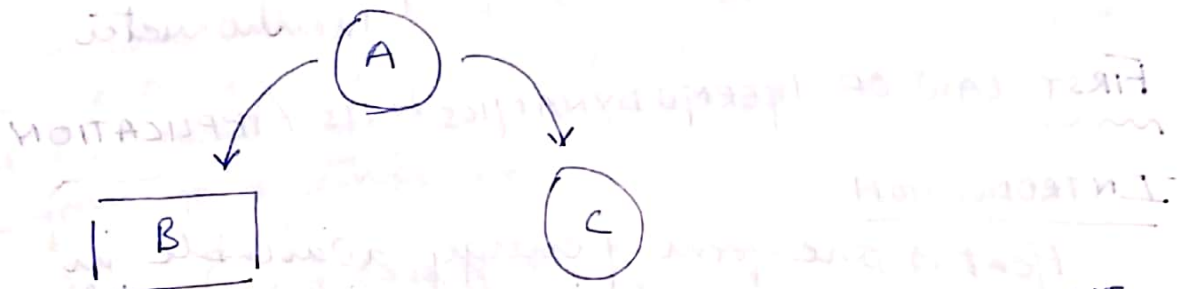
Homogeneous & Heterogeneous system

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

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

ZEROTH LAW:-

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

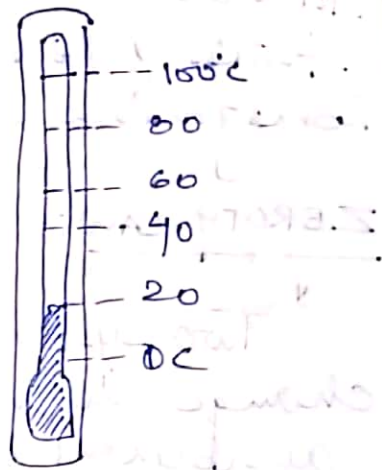


If we apply the concept of temperature equality to an experiment involving these systems A, B & C as shown in Fig an experimental law regarding temp can be established.

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

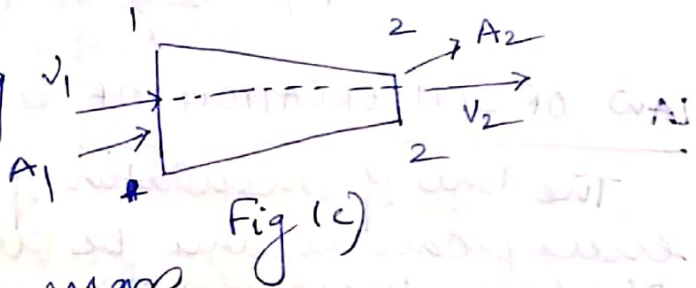
The amount of heat contain in the body is called enthalpy. It is denoted by h .
 u is internal energy and p and v_s are the pressure and specific volume of the fluid taking part in the heat and work reaction.

$$h = u + p v_s$$

LAW OF CONSERVATION OF MASS.

This law states that mass cannot be created or destroyed in the absence of nuclear reaction but may be converted from one form to another form.

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 $\delta t \rightarrow 0$
the mass m flowing through the pipe per unit time is given by
 $m = A \cdot v \cdot \rho$ where $\left(\frac{\delta x}{\delta t} \right)_{\delta t \rightarrow 0} = v$ (the velocity of the fluid)

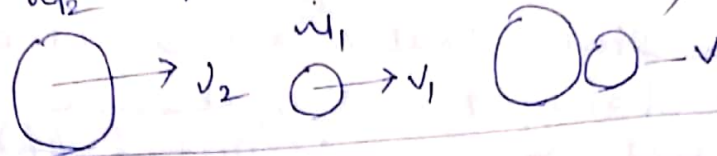
For steady state condition

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

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.



$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v$$

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 states that if a system executes a cycle transferring work and heat through its boundary, then the net work transfer is equivalent to the heat transfer.

$$\text{or } \oint dw = \oint dq$$

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 executes 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

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

$$du = \left(\frac{\delta u}{\delta T}\right)_P \cdot dT + \left(\frac{\delta u}{\delta P}\right)_T \cdot dP$$

$$du = \left(\frac{\delta u}{\delta P}\right)_V \cdot dP + \left(\frac{\delta u}{\delta V}\right)_P \cdot dV$$

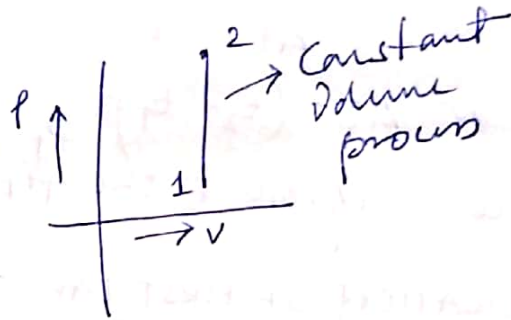
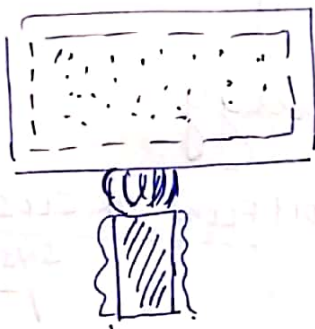
The internal energy of an ideal gas in which there are no forces of molecular interaction does not depend on volume or pressure and so

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

$$\left(\frac{\delta u}{\delta T}\right)_P = \left(\frac{\delta u}{\delta T}\right)_V = \left(\frac{\delta u}{\delta T}\right)_P$$

(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 work done $W = \int_1^2 P dV = 0$ & $dV = 0$

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

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

$$Q = w + (u_2 - u_1) \quad \text{--- (1)}$$

The work done

$$w = \int_1^2 P dv = P(v_2 - v_1)$$

$$Q = \frac{P(v_2 - v_1)}{J_c} + (u_2 - u_1)$$

where J_c is conversion factor which is unity in SI system

$$Q = (u_2 + Pv_2) - (u_1 + Pv_1) = h_2 - h_1 = c_p(T_2 - T_1)$$

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

$$c_p = \frac{\Delta h}{\Delta t} \text{, change in enthalpy per degree change in temp per kg mass}$$

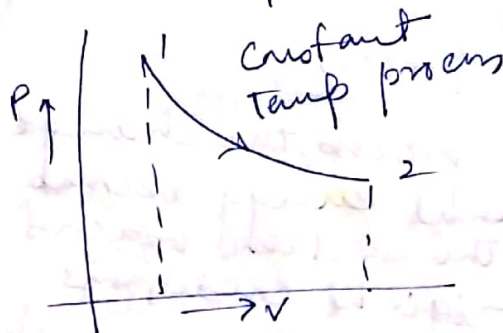
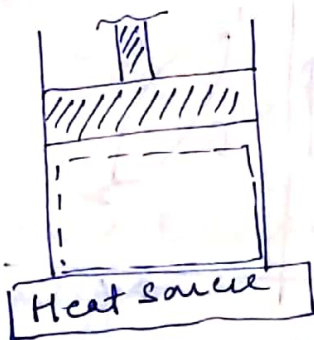
$$\text{Also } Q = c_p(T_2 - T_1)$$

$$= (P_2 v_2 - P_1 v_1) + (u_2 - u_1) = R(T_2 - T_1) + C_v(T_2 - T_1)$$

$$\therefore c_p = R + C_v$$

(d) Reversible Isothermal Process

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



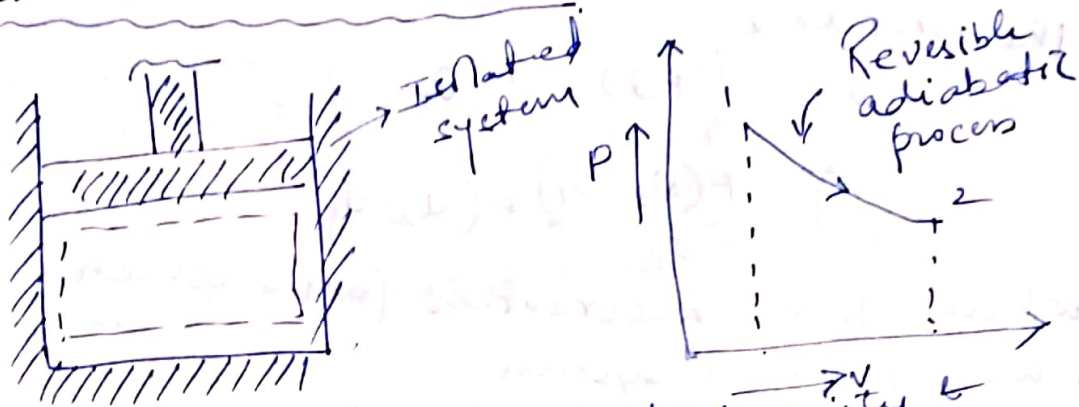
Considering the mass of the system unity and applying the first law to the process

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

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

$$= \int_1^2 P dv$$

(e) Reversible Adiabatic Process



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

$$Q = w + u_2 - u_1$$

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

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

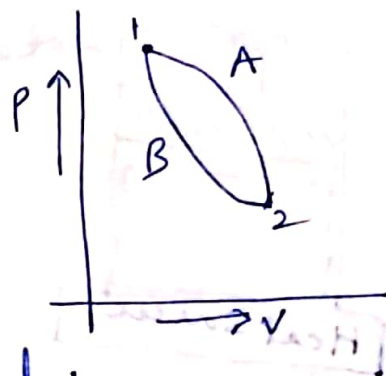
The above equation that the system develops work as the expense of its internal energy

(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

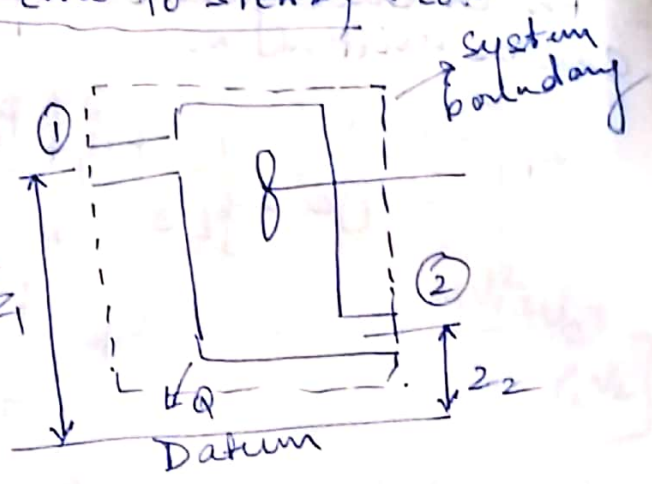
(g) Cyclic Process

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 fig. The following assumptions are made in the system analysis



- (1) The mass flow through the system remains 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 remains 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 surroundings 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

$$E_1 + W + Q = E_2$$

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

For thermodynamic systems, the above equation can be written as

$$m \left[\frac{z_1}{J_c} \cdot \frac{g}{g_c} + \frac{v_1^2}{2g_c J_c} + u_1 + \frac{P_1 v_{s1}}{J_c} \right] \pm W \pm Q = \dots$$

$$m \left[\frac{z_2}{J_c} \cdot \frac{g}{g_c} + \frac{v_2^2}{2g_c J_c} + u_2 + \frac{P_2 v_{s2}}{J_c} \right]$$

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 ($1 \text{ kg-m} / \text{N-s}^2$)
 J_c = Joule constant to convert work unit into heat unit ($J_c = 1 \text{ Nm} / \text{J}$)

- (a) The term $\frac{z}{J_c} \cdot \frac{g}{g_c}$ is the potential energy/unit mass is Joule/kg where z is in metre
- (b) The term $\frac{1}{2} \frac{v^2}{g_c J_c}$ 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 $\frac{P v_s}{J_c}$ 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 $g_c = 1$ is the above equation

$$m \left[z_1 g + \frac{v_1^2}{2} + u_1 + P_1 v_{s1} \right] \pm W \pm Q = m \left[z_2 g + \frac{v_2^2}{2} + u_2 + P_2 v_{s2} \right]$$

By definition $h = u + \frac{P v_s}{J_c} = u + P v_s$ as $J_c = 1$

Substituting this value in the above equation,

$$m \left[z_1 g + \frac{v_1^2}{2} + h_1 \right] \pm w \pm q = m \left[z_2 g + \frac{v_2^2}{2} + h_2 \right]$$

The above 2 equations can also be written as:

$$\left[m z_1 g + \frac{m v_1^2}{2} + u_1 + P_1 v_1 \right] \pm w \pm q = \left[m z_2 g + \frac{m v_2^2}{2} + u_2 + P_2 v_2 \right]$$

where $u_1 = m u_1$ & $u_2 = m u_2$
 $q_1 = m q_1$ and $q_2 = m q_2$

$$\left[m z_1 g + \frac{m v_1^2}{2} + \gamma_1 \right] \pm w \pm q = \left[m z_2 g + \frac{m v_2^2}{2} + \gamma_2 \right]$$

where $\gamma_1 = m h_1$ & $\gamma_2 = m h_2$.

SECOND LAW OF THERMODYNAMICS & CONCEPT OF ENTROPY

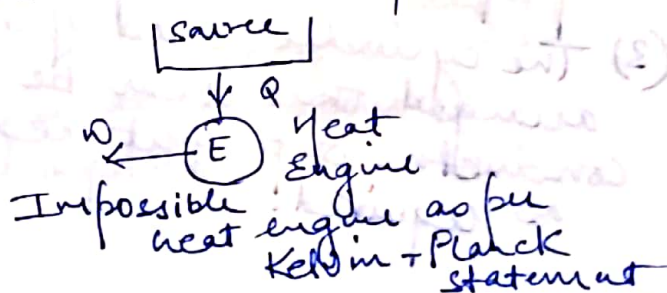
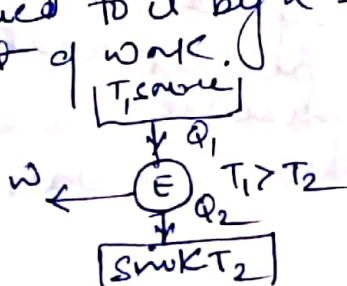
STATEMENTS OF SECOND LAW OF THERMODYNAMICS

1) Kelvin-Planck statement

The Kelvin-Planck 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

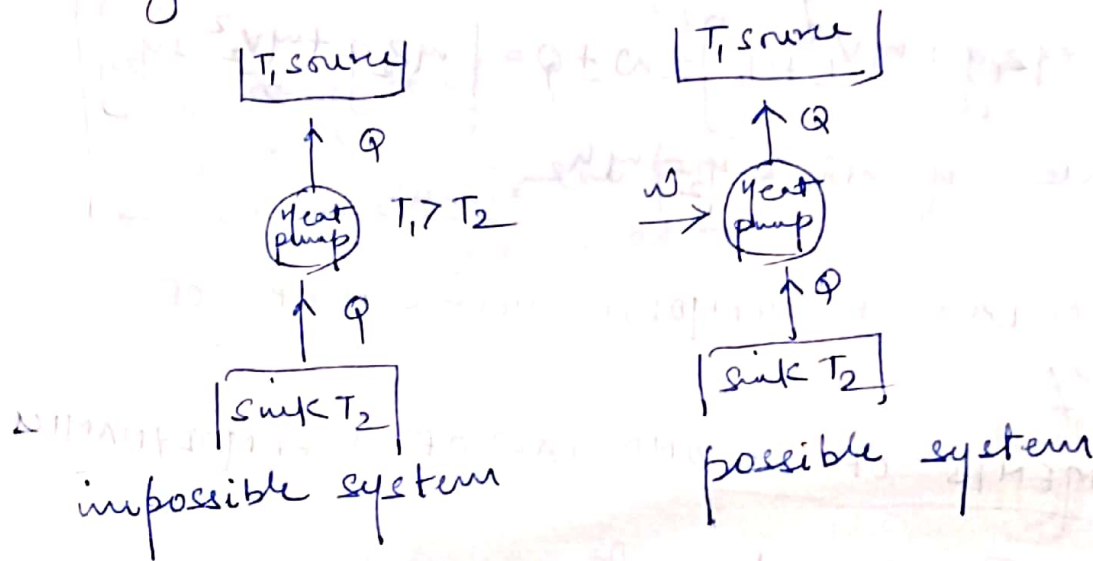
It is impossible to construct an engine working in a cyclic process whose sole effect is the conversion of all the heat energy supplied to it by a source into an equivalent amount of work.



2) Clausius statement

It states 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.



CARNOT CYCLE

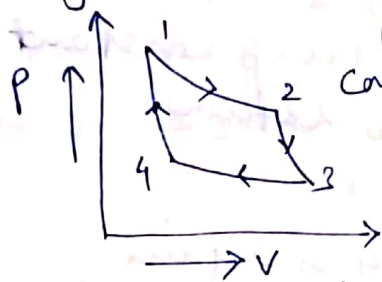
The Carnot cycle consists of four reversible processes: 2 frictionless isothermal and 2 frictionless adiabats.

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

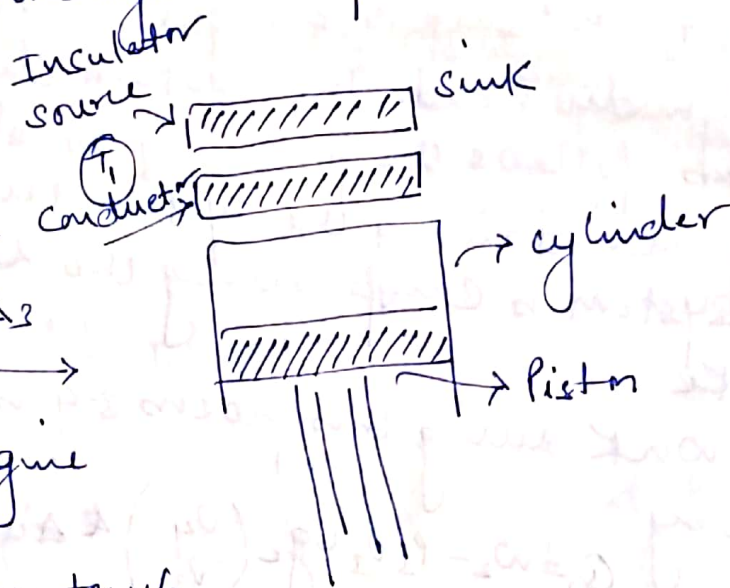
- (1) The piston moving in a cylinder does not encounter any friction during motion.
- (2) The wall of piston and cylinder are considered as perfect heat insulators.
- (3) The cylinder head of the cylinder is so arranged that it can be a perfect heat conductor or perfect heat insulator as required.

(4) The transfer of heat does not affect the temperature 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

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

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

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

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

$$\therefore W = (u_1 - u_2) = \Delta u \text{ (decrease in internal energy)}$$

as $Q=0$

workdone by the system at the expense of decrease in internal system

Using the characteristics gas equation and considering unit mass of the system, we can write the above equation as

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

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

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

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

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

from 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 equations we can write

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

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

$$\eta_c = \frac{\text{Net Output}}{\text{Input}} = \frac{W}{\phi_1}$$

sub the value of W and ϕ_1 we get

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

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

provides a method based on calculation, of explaining why certain energy transformations are impossible and of identifying the direction of any spontaneous process.

Consider a cycle shown in Fig. which is made of 2 reversible processes following the path a-b. The reversible cycle is 1-a-2-b-1. As we have proved for a reversible cycle

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

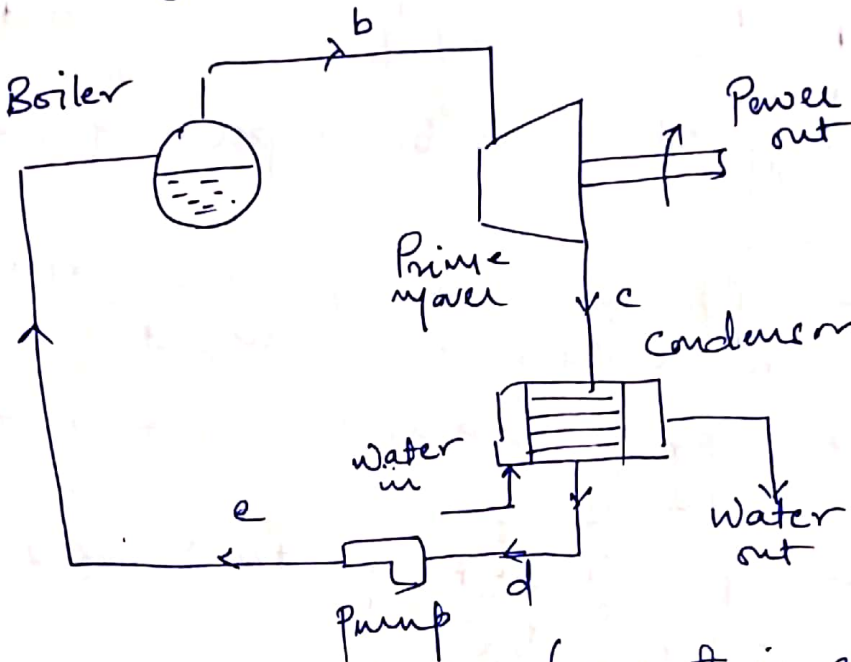
$$\therefore \int_{1(a)}^2 \left(\frac{dQ}{T} \right) = - \int_{2(b)}^1 \left(\frac{dQ}{T} \right) = \int_{1(b)}^2 \left(\frac{dQ}{T} \right)$$

This indicates 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 this property.

This property is called "entropy" and denoted by s and defined by

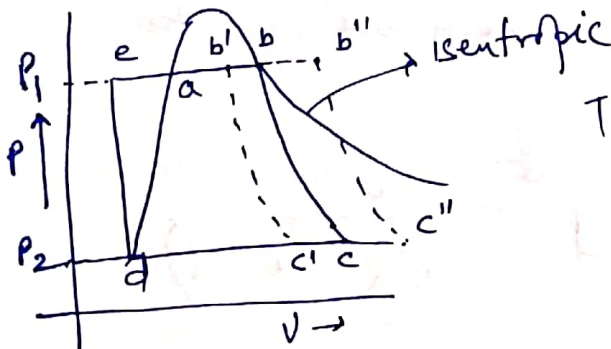
$$ds = \left(\frac{dQ}{T} \right)_R \quad \text{or} \quad s_2 - s_1 = \int_{1(R)}^2 \left(\frac{dQ}{T} \right)$$

Rankine cycle

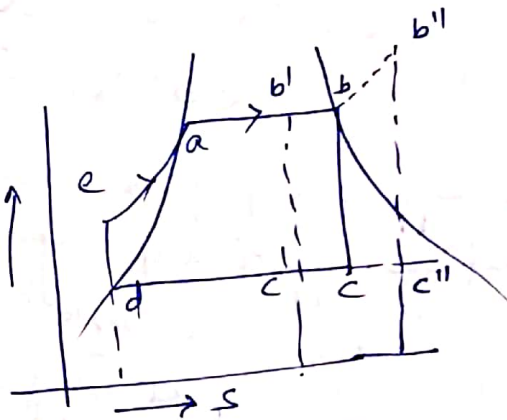


The arrangement of component in a steam power plant working on Rankine cycle

The line diagram of the component of the steam power plant working on Rankine cycle is shown in Fig while the Rankine 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 shown is P-V and T-S diagram

Let h_b = specific enthalpy of steam at point 'b'
 h_c = specific enthalpy of steam at point 'c'
 v_f = specific volume of water at point d or e
 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 work done by the pump per kg of water pumped

Work done per kg of steam in the prime mover

$$= h_b - h_c$$

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

$$w_p = v_w (p_1 - p_2) \text{ kJ/kg of water}$$

$$= v_w (p_1 - p_2) 10^{-3} \text{ kJ/kg; where } p_1 \text{ \& } p_2 \text{ are in } \text{N/m}^2$$

$$= 100 v_w (p_1 - p_2) \text{ kJ where } p_1 \text{ \& } p_2 \text{ are in bars}$$

and v_w is the specific volume of saturated water at pressure p_2

\therefore 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

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

Internal combustion engine

Any machine which derives heat energy from the combustion of fuel and converts part of this energy into mechanical work is known as a heat engine. Heat engines are mainly divided into 2 groups viz external combustion engine and internal combustion engine.

Classification of I.C engine

The internal combustion engines are classified according to

(1) Cycle of Operation

- (a) Two stroke engine
- (b) Four stroke engine

(2) Cycle of Operation

- (a) Otto cycle (b) Diesel cycle (c) Dual cycle

(3) The Fuel used

- (a) Petrol engine (b) Diesel engine (c) Gas engine

(4) The Method of Ignition

- (a) Spark Ignition engine (S.I engine)
- (b) Compression Ignition engine

(5) Method of cooling

- (a) Air cooled engine
- (b) Water cooled engine

(6) The Method of Governing

- (a) Quantity governing
- (b) Quality governing
- (c) Hit & Miss governing

Heat

(7) The use of Engine

- (a) Stationary engine
- (b) Automobile engine or engine for road vehicle
- (c) Marine engine
- (d) Aero-engine
- (e) Locomotive engine

(8) The Arrangement of the cylinder

- (a) Inline Engine
- (b) V-type
- (c) Opposed piston engine
- (d) Radial engine
- (e) Rotary engine

MODES OF HEAT TRANSFER

Heat transfer can be defined as the transmission of heat energy from one region to another as a result of temp difference or gradient.

The modes of heat transfer are conduction, convection and radiation. In all heat transfer modes, a temp difference must exist to cause heat flow and heat always flows in the direction of lower temp.

Heat conduction is due to the property of matter which causes heat energy to flow through the matter even if the body is impenetrable to any kind of radiation and its part are not in motion relative to one another.

Heat convection is due to the property of moving matter to carry heat energy from higher temp regions to low temp regions as internal energy.

Heat radiation is due to the property of matter to emit and absorb different kind of electromagnetic radiation. The radiation heat transfer b/w 2 bodies take place without any carrying medium as required in conduction & convection.

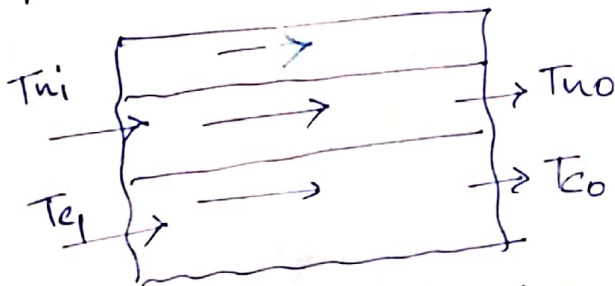
HEAT EXCHANGER

A heat exchanger is an equipment to transfer the energy from a hot fluid to a cold fluid with max rate and minimum investment and running cost.

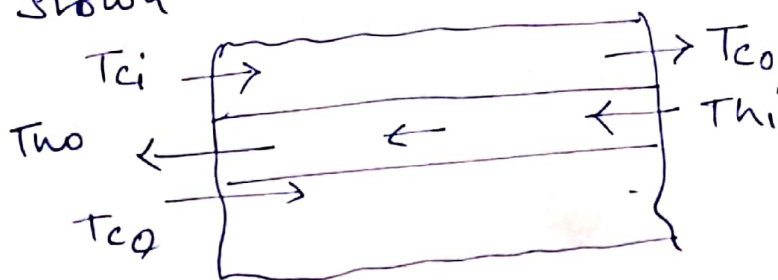
The heat exchangers are generally divided into 3 group according to the direction of the flow of fluid.

- (1) Parallel flow heat exchanger
- (2) Counter-flow heat exchanger
- (3) Cross flow heat exchanger

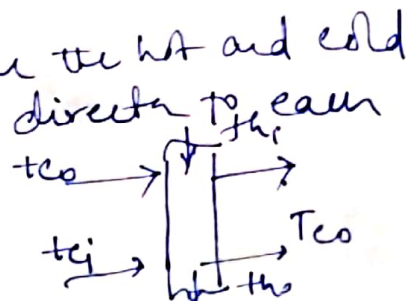
In parallel flow heat exchanger the hot & cold fluid flow in the same direction.



The counter flow heat exchanger the hot and cold fluid flow in the opposite directions shown



In cross flow heat exchanger the hot and cold fluid flow in perpendicular direction to each other.



The heat transferred from a hot fluid to the cold fluid in a heat exchanger is given by

$$Q = UA(\Delta T)$$

U = overall heat transfer

A = surface area.

ΔT = Mean temp diff