Civinnovate

Discover, Learn, and Innovate in Civil Engineering ction

Defination:-

Engineering thermodynamics:

Thermodynamics is the branch of applied science which deals with energy process by gases & vapours, their conversion in terms of heat and work, and its relationship with various properties of system.

The most common application of thermodynamics is head engine and refrigerator.

IMP TU BE2070

* Any thermodynamic system can be analysed in two ways: microscopic viewpoint and macroscopic viewpoint.

Microscopic view	Macroscopic view.
→ In this view, system is analysed with reference to its molecular structure or molecular behavior.	→ In this view, system is analysed with reference to certain measurable properties
→ Calculation is time consuming & tedius in this view	→ Relatively faster & simpler.
→ This approach is usually used in statistical thermodynamics and used by pure scientist.	→ This approach is used in applied thermodynamics and used by engineers.

Terminologies :→

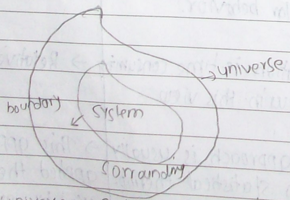
⊛ Thermodynamics system, Sorrounding, Boundary & universe.

⇒ Any Component or a collection of certain components which is performing certain specific task or activity is called a system. or, A part of universe which is to be studied or analysed.

All the material or medium outside the system is called its sorrounding and.

The medium which separates system from its sorrounding is called boundary.

The system & sorrounding taken together is called universe.



universe = System + Sorrounding

Types of System :-

ⓐ Closed System :→

System in which energy transfer can take place but mass cannot is called a closed System. eg:- piston cylinder device, in which heat and work can cross the boundary of the system but gas cannot escape out from system.

↳ Total mass of a closed system always remains constant therefore any closed System can be completely described by the properties of particular amt. of mass inside the system. Hence, a closed System is called control mass (C.M)

ⓑ open system :→

System in which both mass and energy transfer can take place is called an open system.

eg:- air compressor.

↳ For the study of such system, we select some specified region and analyze this region with reference to thermodynamic properties Hence, an open system is also sometime called a control volume (C.V)

Ⓒ Isolated System:→

System in which neither mass nor energy transfer can take place is called an isolated system.

eg:→ A closed, rigid and insulated container.

Thermodynamic properties:→

Any parameter or variable used to describe a thermodyamic system is called a thermodynamic property.

Eg:- pressure (P), Tempr (T), volume (V), internal energy (U), total energy (E), enthalpy (H) and entropy (S).

Types:→

① Intensive property:→

The thermodynamic property which is independent of mass or part of the system considered is called an intensive property. eg: P, T

② Extensive:→

The thermodynamic property which is dependent of mass or part of system considered is called an extensive property.

e.g. U, Volume (V), H, S, etc.

↳ ∵ Extensive properties are proportional (dependent) to mass so they can be converted into intensive form by dividing its value by mass. The ratio of an extensive property to mass is called sepecific value of that property.

eg:- $e = \frac{E}{m}$ is specific total energy.

imp * Thermodynamic equilibrium:→

A system is said to be in a thermodynamic equilibrium if there is no change in any properties of the system when it is isolated from its sorrounding.

i.e it should satisfy thermal equim → ($\Delta T = 0$)

mechanical equilibrium $(\Delta p = 0)$ and chemical equilibrium → no chemical rxn.

Some common properties:-

1 **Specific volume:-**

The volume per unit mass of the substance (reciprocal of property density). denoted by v and expressed in x^3/kg.

$$v = \frac{V}{m}$$

→ In thermodynamics, most of the time we deal with gas and vapour which have very low density. Hence it is appropriate to express property or state relationship of such substance in terms of specific volume (v).

2. **Pressure:-** Force per unit area. (p), N/m^2 or pascal (pa) also in bar or atm.

$1 \text{ bar} = 100 \text{ kpa} = 10^5 \text{ pa} \simeq 1 \text{ atm}.$

$1 \text{ atm} = 101.325 \text{ kpa} = 1.01325 \times 10^5 \text{ pa}.$

⇒ We deal with three pressure terms in the thermodynamics: atmospheric pressure (P_{atm}),

gauge pressure (P_{gauge}) and absolute pressure (P_{abs}):-

↳ pressure exerted by ambient air on any surface is called atmospheric pressure. It is measured by barometer. Barometer gives pressure in terms of height of mercury column.

h_{baro} as;

$$\boxed{P_{atm} = \rho g h_{baro}} \quad \text{——} ①$$

where, ρ = density of mercury.

g = local gravitation accn.

↳ pressure of any system with reference to atm pressure is called gauge pressure. Gauge pressure is usually measured by pressure gauge or manometer which gives pressure reading directly in pa or bar.

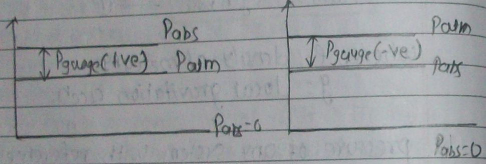
↳ Manometer gives gauge pressure of a system in terms of height of certain manometric fluid h_{mano} as:

$$\boxed{P_{gauge} = \rho g h_{mano}} \quad \text{——} (ii)$$

ρ = density of manometric fluid.

↳ pressure of any system expressed relative to a perfect vacuum is called absolute pressure. Hence Patm, Pgauge & Pabs can be represented on a pressure scale as shown below and are related as:-

$$\boxed{P_{abs} = P_{atm} + P_{gauge}} \quad \text{--- ②}$$



(3) Temperature:→

A degree of hotness or coldness of a system. also, a property of a system which defines the direction and magnitude of heat transfer.

Tempr is measured by thermometer in various scale as below reln.

$$\frac{C-0}{100-0} = \frac{F-32}{212-32} = \frac{K-273}{373-273}$$

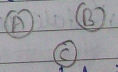
or $$\boxed{\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5}}$$

Equality of temperature:→

Two systems are said to be have equal tempr if there is no change in any properties of both the system when they are brought in contanct with each other.

Zeroth law of thermodynamics:→

Consider 3 system A, B and C as in fig. If A and C are brought in contanct with each other and there is no change in any properties of both, then we can conclude both A and C have same tempr. Again if B and C are brought in contact with each other and there is no change in any properties of both system the we can say both B&C have same temperature. Then without performing 3rd expt. we can conclude A and B also have same temp.



This fundamental is called zeroth law of thermodynamic which states as:-

When two systems are separately in thermal equlbm with a third system, then these two system should be also in thermal equilibrium

Energy eqn for a flow system (open system)

⇒ let us Consider an open system bounded betn A_1A_2 to B_1B_2 of area of cross section A be displaced from A_1A_2 to B_1B_2 of 'l' displacement.

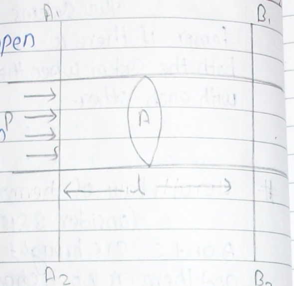


Fig: open system

Then,
From pure science,
workdone = Force x displacement

$$= F \times l = p \times A \times l$$

$$\boxed{w = pv}$$, v → displaced or changed in volume.

process =

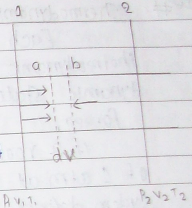
when a system undergoes change from one st. point to another state point. it is called process

cycle :-

when a system after undergoing a number of process attains its initial or original condition it is called cycle.

Quasi - Static process :→

⇒ Here,
defn :-
when the system undergoes a change in such a way that its final state (condn) is almost (near) to the initial (original) equilibrium condn is called Quasi - static process.



Now,
Consider a closed system be bounded from 1 to 2 i.e from $P_1V_1T_1$ to $P_2V_2T_2$ then, let the system is displaced small by dv volume then.

$$dw = P \times dv$$

$$w = \int^{2} p\,dv \quad - ②$$

value of 'energy to society' :-

↳ Basic consumption, pattern indicates development
↳ Basic commodity
↳ Social impact / Environment impact

IMP # Thermodynamic State :→

Each unique condition at which a thermodynamic system exist is called a therm dynamic state.

For eg.

If a room has a tempr of 27°C & press of 1 atm at any instant, This condition of a system defined by $T_1 = 27°C$ & $P_1 = 1$ atm can specified as state 1 of the system. If a room heater is turned on for certain internal, and after some time room might have 30°C. Then th condition of the system is defined by $T_2 = 30°C$ & $P_2 = 1$ atm can be specified as state 2 of the system.

IMP After defining thermodynamic state, we can explain the features of thermodynamic property a

↳ (a) A variable is a property, if and only if it has a single value at each equilm state.

↳ (b) A variable is a property if and only if, a change in its value betn any two prescribed states is independent of path.

Eg:- pressure, any thermodynamic system cannot have multiple values of pressure at any instant.

Hence, pressure is thermodynamic property.

Again, work, it will have different values for different path between same initial and final states ($W_A > W_B > W_C$) as in below fig. Hence, work being a path dependent variable is not a thermodynamic property.

IMP ⇒ All the thermodynamic properties depend only on the end states and they are called state functions.

⇒ Variable such as work, heat etc. depend not only on the end states but also on the path are called path functions.

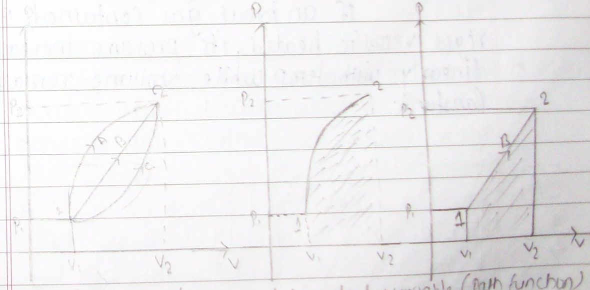


Fig: work being pathdependent variable (path function)

#1) Thermodynamic process:→

The path followed by a system when i undergoes from one equilibrium state to anoth is called a thermodynamic process.

OR

A locus of states through which system passes while undergoing change from one equilibr-ium state to another.

These process are described with the help of property diagrams such as P-V, T-V, P-T, h-s T-S, P-h diagrams etc.

Now,

Constant volume heating process:→

If an ideal gas contained in a rigid vessel is heated, its pressure increases linearly with tempr while volume remains constant.

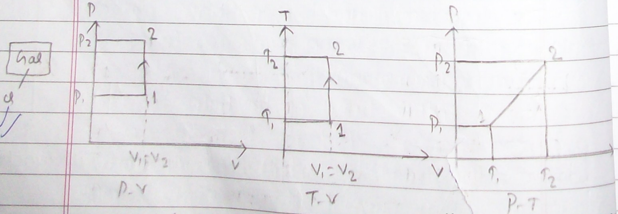


Fig:- Constant volume heating process

Constant pressure heating process:→

If an ideal gas contained in a freely moving frictionless piston cylinder is heated, its volume increases linearly with tempr while its pressure remains constant as in below fig:-

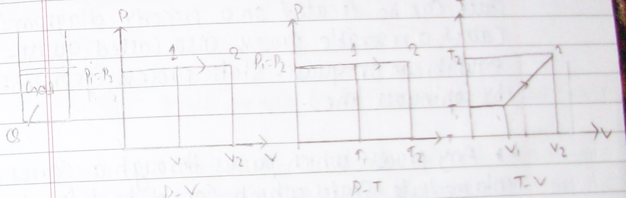


Fig:- Constant pressure heating process.

Constant tempr heating process:–

If an ideal gas contained in a piston cylinder device is heated under const tempr, its pressure decreases and volume increases as below:–

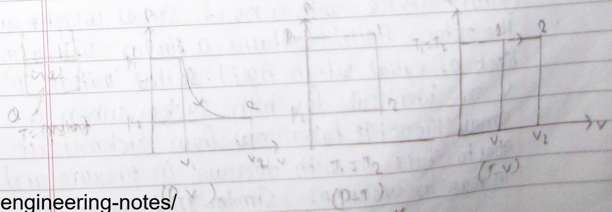


fig:- Const. tempr heating process

imp → with reference to intermediate states, thermodynam process can be classified as:- reversible & irreversible

↳ Any process which passes through a series of intermediate state such that each intermediate state can be located on a property diagram is called a reversible process. also called quasi-equilibrium or quasi-static process. (represented by continuous line).

↳ Any process which passes through a series of intermediate states which cannot be defined or be located on a property diagram is called an irreversible process. (by broken line)

Expln

Consider a piston cylinder arrangements shown in fig(i) and fig(ii). Fig(i) contains a piston cylinder device with a no of small weight above the piston. Fig(ii) contains a similar with a single block of equal wt. in fig(i). So that initial 'p' & v are identical for both system when a small block is taken out from system(i) it goes to state a with decrease in pressure and increase in volume. Similarly, if we go on removing weight, its system passes through states b, c, d - - - - finally to state 2 as:

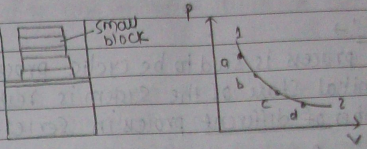


Fig1- quasi- equilibrium (reversible) process. (Slow transition)

While in case of fig(ii), we can either keep a single block above piston or can take it out. if we take out, the system reaches to state 2. instantaneously i.e

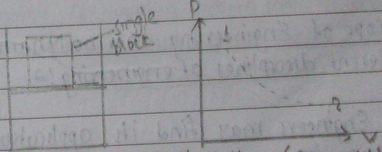


Fig ii-Rapid transition (irreversible)

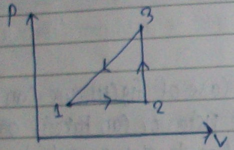
Now,

For(i), we can take system back from any intermediate state to the reverse direction. so it is a reversible process.

While in case of (ii), there is no possibility of taking system back from any intermediate states hence it is an irreversible process.

Cyclic:→

A process is said to be cyclic process, if the initial state of the system is restored by a number of different process in series.



imp # Scope of Engineering thermodynamics in different disciplines of engineering:→

↳ Civil Engineers may find its application while choosing layout of a building on a provided land space such that energy requirement fo heating and lighting is minimum.

↳ Electrical, electronics and computer engineers may find its application while selecting proper cooling system for the diff. electrical or electronic devices.

↳ Mechanical engineers may find its application while designing different components of power plant system, heating and ventilating units etc.

Value of energy to society:-

Energy plays a unique and critical role in the word; no activity of any kind can take place without the movement or conversion of energy.

(remaing expn see page-1 in book)
& try to explain points:-

↳ Basic commodity
↳ Energy consumption pattern indicates development.
↳ Social & Env. impact etc.

State ~~path~~ function	~~State~~ path function
# All the thermodynamic property depends only on the end state and are called path function.	# All the thermodynamic property depends not only on the end state but also on the path are called state function.
# The cyclic integral of point function is zero.	# The cyclic integral of path function is not zero.

work and heat are

pressure, volume & tempr are point function.

T.U
Past question

(1) diff betn path function & point function (State function) [4]

2) " " microscopic & macroscopic view point in Engineering thermodynamics. [4]

(3) write features of thermodynamic property.

(4) diff. betn closed & open system with eq. [4]

(5) State & explain equality of tempr. Also state Zeroth law [4]

(6) State & explain 3 type of thermodynamic system.

⑦ Define thermodynamic process. Sketch p-v, T-v, p-T diagram for an Ideal gas undergoing const pressure heating process.

⑧ Define thermodynamic property and state. list two features of a thermodynamic property [4]

Chapter-2

Energy & Energy Transfer

↳ Energy can be defined as the capacity of a system to exert (provide) for a certain interval.
pressure

Energies

Stored energy
(i) Internal energy.
(ii) P.E
(iii) K.E

Transient energy
(i) Heat transfer
(ii) work-transfer.

↳ The Energy which remains with in the system boundary as inherent property of the system is called stored energy. eg: I.E, P.E, K.E

Stored energy has unique value for each equilibrium state and are independent of path and hence are thermodynamic property.

↳ The Energy which can cross the boundry of system during a thermodynamic process is called transient energy. eg: work transfer, Heat transfer.

They donot have unique values for each

equlibrium state as they depend not only on the properties of system but also on property of the sorrounding. They are dependend on path and hence are not thermodynamic property.

Stored Energy:-

i) Internal energy:-(U)

It is the energy of the system due to molecular activities or also, it is the summation of molecular potential energy and molecular K.E. As molecular activity increases with tempr, internal energy of the system also increases with increase in tempr.

(ii) P.E: $P.E = mgh$ —(i)

(iii) K.E : $K.E = \frac{1}{2}mu^2$ —(ii)

Total Energy:-

$$E = U + PE + KE = U + mgh + \frac{1}{2}mu^2$$

So,

Specific total energy, $\boxed{(e) = \frac{E}{m} = u + gh + \frac{1}{2}u^2}$

Transient energy:-

VI (i) Heat transfer:-(Q):-

Transfer of energy, without transfer of mass, because of temprature difference between the system and the sorrounding is called heat transfer.

In thermodynamics, heat transfered to the system is taken as +ve and heat lost from the system is taken as -ve.

VVI (ii) work transfer:→

⊛ In classical mechanics, work is said to be done if certain system is displaced by a force in the direction of force. i.e

$$W = \int_1^2 F\,d\vec{s} \quad \text{—(i)}$$

⇒ This defn is not directly applicable for all thermodynamic process belausing during some processes energy is transfered without observable microscopic displacement.

So,

↳ ⊛ Modern defn :→ work transfer is the transfer of energy, without transfer of mass, because of any [illegible] difference other than temperature

↳ also, works flows from a system during a given operation if the sole effect external to the system could be reduced to raise of a weight.

Expression for displacement work Transfer:→

⇒ Consider a piston cylinder device containing a gas. during process I to II, the piston is displaced by $d\vec{s}$

Now, According to classical defn,

work transfer is,

$$W = \int_1^2 F.d\vec{s}$$

where F is force provided by gas pressure.

i.e $F = PA$ so, we get

$$W = \int_1^2 PA\,d\vec{s}$$

$$\boxed{\therefore W = \int_{V_1}^{V_2} PdV \quad \text{--- (i)}}$$

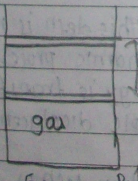


Fig:

→ can also be determind by area covered by P-V curve w.r.t V-axis

⇒ We can further derive expressions for work transfer for different specific conditions.

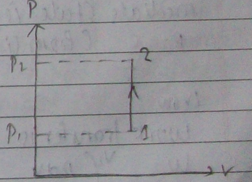
ⓐ Constant volume (isochoric) process:→

Here,

Volume(V) = const (c) – (i)

So, also, the area covered by P-V curve is zero for such process, hence, work transfer is zero. as there is no displacement during const. volume. ($dV = 0$)

i.e $W = \int_{V_1}^{V_2} PdV = 0$



→ Constant volume heating process.

ⓑ Constant pressure:→

Here,

$$W = \int_{V_1}^{V_2} PdV$$

$$= P\int_{V_1}^{V_2} dV = P.[V]_{V_1}^{V_2}$$

Isobaric

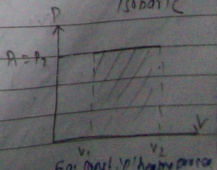


Fig: Const. 'p' heating process

$$\boxed{W = p(V_2 - V_1)}$$

→ which is also given by the area under p-v curve as shown above.

ⓒ Constant temperature process! (isothermal)

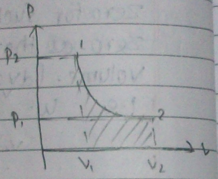
⇒ T = Constant

pv = const. Now, —(i)

$\therefore p_1 v_1 = p_2 v_2 = pv$

∴ pressure at any intermediate state is given by

$p = \frac{c}{v}$ [from (i)]



Now,

work transfer is

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

$$= \int_{v_1}^{v_2} \frac{c}{v}\,dv$$

$$= c\int_{v_1}^{v_1} \frac{dv}{v}$$

$= p_1 v_1 [\ln v]_{v_1}^{v_2}$ [∵ from(i) pv = c]

$W = p_1 v_1 \ln[v_2/v_1]$

$$\boxed{W = p_2 v_2 \ln(v_2/v_1) = p_2 v_2 \ln(p_1/p_2) \quad \text{— (ii)}}$$

ⓓ polytropic process:→

Thermodynamic process which follows the relation pv^n = Const is called a polytropic process and index n is called polytropic index. It is generalized eqn for thermodynamics. i.e

value of (n)	eqn	process
0	p = constant	isobaric
1	pv = constant	isothermal
γ	pv^γ = constant	adiabatic
∞	v = constant	isochoric

Now,

pressure-volume (p-v) relation for initial, final and any intermediate state during a polytropic process is given by,

$p_1 v_1^n = p_2 v_2^n = pv^n$

$\therefore p = \frac{p_1 v_1^\gamma}{v^n}$ — ①

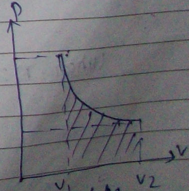


Fig. adiabatic

Now,
Work transfer is

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

$$\int_{v_1}^{v_2} \frac{p_1 v_1^n}{v^n}\,dv = p_1 v_1^n \int_{v_1}^{v_2} v^n\,dv$$

$$= \frac{p_1 v_1^n [v_2^{1-n} - v_1^{1-n}]}{1-n} = p_1 v_1^n \left[\frac{v^{-n+1}}{1-n}\right]_{v_1}^{v_2}$$

$$= \frac{p_1 v_1^n}{1-n}[v_2^{1-n} - v_1^{1-n}]$$

$$\boxed{p_1 v_1^n = p_2 v_2^n = c} \leftarrow = p_2 v_2^n v_2^{1-n} - p_1 v_1^n v_1^{1-n}$$

$$= \frac{p_2 v_2 - p_1 v_1}{1-n}$$

$$\boxed{\therefore W = \frac{p_1 v_1 - p_2 v_2}{n-1}}$$

When $n = \gamma \rightarrow$ adiabatic process.

power:- (watt)

It is defined as the rate of energy transfer

power due to work transfer $(P) = \lim_{\Delta t \to 0} \frac{dW}{\Delta t}$ — ①

" " Heat " $(P) = \lim_{\Delta t \to 0} \frac{dQ}{\Delta t}$ — ⑪

Some part of energy is consumed by the system itself called internal energy.

[For self acting machine]

$\boxed{du = m \times c_v \times dT}$

- → similarities of heat transfer
- → Both are forms of energy and are transient type.
- → physical they are equivalent their unit is joule.
- → For cyclic process, heat & work are equal
- → Heat may be cause of work or vice-versa.

TU
B.E

Ch-2

Question

1) Define heat transfer & work transfer. Also mention Similarities & diff. betn heat & work [4-4]

2) Define energy & power. differentiate between stored & transient energy with examples [4]

③ Define total energy of a System.

4) Derive an expression for work transfer for any process on a piston cylinder. Reduce it to get the expression for work transfer during a polytropic process [4]

5) Derive thermodynamic process.

6) Also mention Sign convention used in the analysis of thermodynamic problems

Chapter 3

Properties of Common Substance:

Introduction:→

⇒ One of the major area of the applied thermodynamic is the property analysis of the common substance that can be used to transfer energy.

For most of the applications, working substances will be in the gaseous state, vapour state or in the form of liquid and vapour. If the working substance is in gaseous state, it is usually modelled by an an ideal gas eqn. It is in liquid state, vapour state or mixture. Its properties cannot be evaluated by using mathematical eqn and for this purpose we have to use experiment data.

⊕ Pure substance:→

A system is said to be composed of pure substance if it is:

(i) homogeneous in composition.
(ii) homogeneous in chemical aggregation.
(iii) Invariable in chemical aggregation.

↳ Homogeneous in chem. composition means the proportion of the constituent elements of the substance should be same throughout the system.

↳ Homogeneous in chemical aggregation means that Constituent elements of the substance should be

combined in similar manner in all sampl of system.
and,

↳ Invariable in chemical aggregation means that the state of homogeneity should not change with time.

State postulates:→

For a pure substance, we can determine all thermodynamic properties if two independent thermodynamic properties are given. This specia feature of a pure substance is called state postulate or two-property rule which can be stated as:-

"Two independent thermodynamic properties are sufficient to establish a stable thermodynamic state of a system composed of a pure substance."

eg:- If P & V are given the T can be determined

It can also be stated in terms of intensive properties as:

"Two independent intensive thermodynamic properties are sufficient to establish a stable thermodynamic state of pure substance"

eg:- T can be determined if P and specific (sp) volume (v) are given.

Ideal gas and Relations:→

A perfect gas or an ideal gas is defined as gas having no forces of molecular attraction. A gas which follow ideal gas law & eqn of all ranges of P & T can be considered as an ideal gas but no such gas exists in the nature.

1) Boyle's law:-

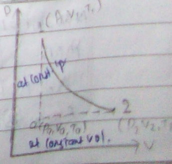
At const T, $P \propto \frac{1}{V}$ — ① ⇒ $\boxed{PV = K}$ = $\boxed{P_1V_1 = P_2V_2}$

2) Charles law (Gay-lussac's law):→

↳ At const P, $V \propto (T)_P$ — ①

At const V, $P \propto (T)_V$ — (ii)

3) Equation of state or combined gas law:-



⇒ let us consider a closed system undergoing change from state 1 to 2. Assuming that final condition is attained with the system undergoing change first at const volume from state

1 to a and then at const pressure from state a to 2. Then.

For process (1 to a) i.e constant volume ($v_1 = v_a$)

$$\frac{P_a}{P_1} = \frac{T_a}{T_1} \quad \text{— (i) (By charles law)}$$

For const. pressure line or process (a to 2)

$P_a = P_2$

or, $$\frac{V_a}{V_2} = \frac{T_a}{T_2} \quad \text{— (ii)}$$ By charles law,

Now,

dividing eqn ② ÷ eqn ①

$$\frac{P_a}{P_1} \times \frac{V_2}{V_a} = \frac{T_2}{T_1}$$

or, $$\frac{P_2V_2}{P_1V_1} = \frac{T_2}{T_1}$$

(52) or $$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

$\Rightarrow \frac{PV}{T} =$ constant (R)

or $\boxed{PV = RT}$ — A

where R is gas const.

Now, when mass (m) is introduced in the eqn. then. $\boxed{PV = mR_cT}$ — Ⓑ

R_c is known as characteristic gas constant & eq Ⓑ is called characteristic gas eqn.

Two phase (Liquid and vapour system)

1) Saturation curve on T-v diagram :⇒

→ specific volume

⇒ Consider a frictionless constant pressure piston - cylinder device, shown in fig. below containing some amt. of water at atmospheric condition specified by state A as in curve ⓑ. If the weight of piston is negligible, pressure remains constant at 1 atm throughout the ~~press~~. process.

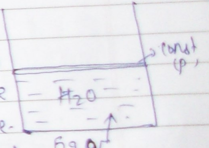


Fig ⓑ

Now,

Heat is supplied to the system from an external source. The tempr of the water increases with slight increasement of specific volume (v), which is represented by line AB in curve ⓑ. This trend continues until its tempr reaches to 100°C, state B. This particular state of H_2O is called saturated liquid state, because, further heat addition causes it to evaporate. Now, Evaporation process is represented by line BC, during which P and T remain constant and specific volume of the substance increases due to intermolecular expansion. After the absorption of complete latent heat, H_2O gets completely converted into vapour, state C, which is called saturated vapour state. When Saturated vapour is further heated, its tempr increases with Sp volume shown by line CD and the state is called Superheated vapor.

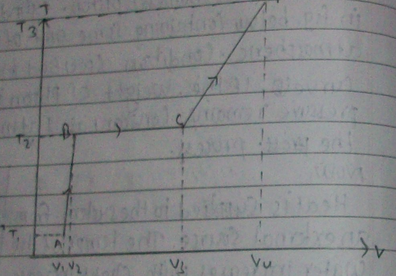
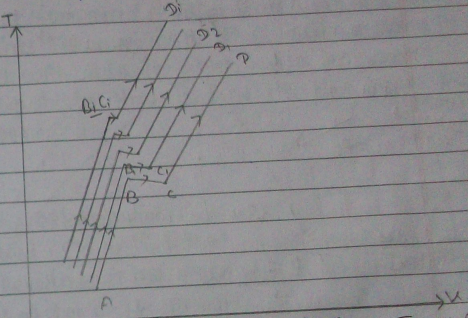


Fig:-(b) T-V Diagram for Const. pressure heating of water

Now

⇒ It is similar heating process is carried out at high pressure, by putting some weight above the piston, evaporation takes places relatively at higher temperature as shown in fig (c) i.e the length of line BC goes on decreasing if we evaporate water at higher pressures. At some particular pressure, length of line BC becomes zero i.e Saturated liq. state (B) and Saturated vapour state (C) [illegible]

This particular state of substance is called the critical point at which both Saturated liq. & Saturated vapour have identical properties.



↳ Fig:-(c): T-V Diagram for heating water at diff pressure

⇒ The curve joining the Saturated liquid state is called Saturated liquid line and the curve joining the Saturated vapour states is called Saturated vaporline. The entire curve so formed as below fig. (d) is called a Saturation curve; The region left to the Saturated liquid line is called Compressed liqued or Subcooled liq. region and the region right to the Saturated vapor line is called Superheated vapor region and the region with in curve is called two-phase mixture region.

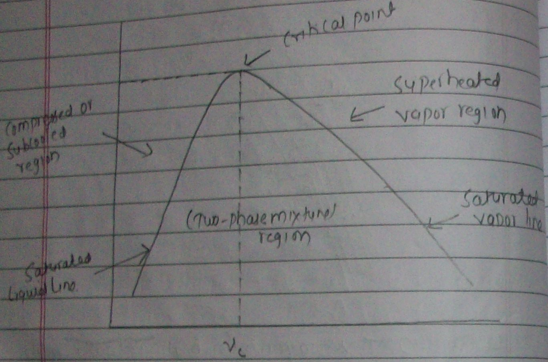


Fig:- Saturation curve for two-phase mixture on T-V diagram.

② Saturation curve on p-v diagram:→

⇒ Consider a piston cylinder arrangement containing water at compressed liquid state (say at 5 atm and 100°C) as shown in fig (a). This system is placed in contact with a source which has a temperature slightly higher than that of the H_2O inside the cylinder.

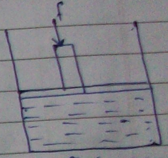


Fig (a) Arrangement for const. Tempr exp. of H_2O

Now:-

If the external force f is reduced slowly such that temperature is maintained const at 100°C, its pressure decreases and there will be slight increasement in its specific volume as shown by line AB in curve (b). This trend continues until its pressure reduces to 1 atm i.e it reaches to saturated liquid state B. When saturated liquid take heat from the source, it gets evaporated and its specific volume increases until it reaches to saturated vapour state C, while its pressure and tempr remains constant as shown by line BC in fig. (b). If pressure is further reduced from state C, its [illegible] increases as shown by CD in fig. (b)

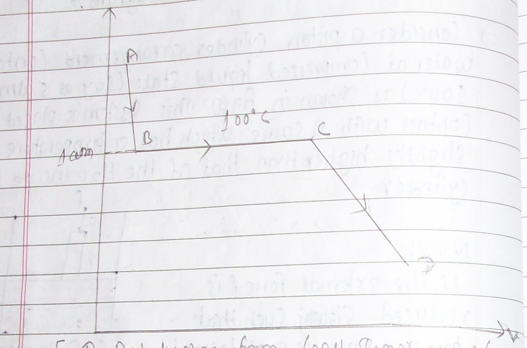


Fig B P-V diagram from Const Tempr exp of water

Now

⇒ If we repeat similar process at const higher temperatures evaporation takes place corresponding at higher pressures and the length of BC goes on decreasing and at state come at which length of BC becomes zero i.e B_i & C_i coincide and the point is called critical point at which both saturated liq. & saturated vapour state gets coincide as shown below fig. ©

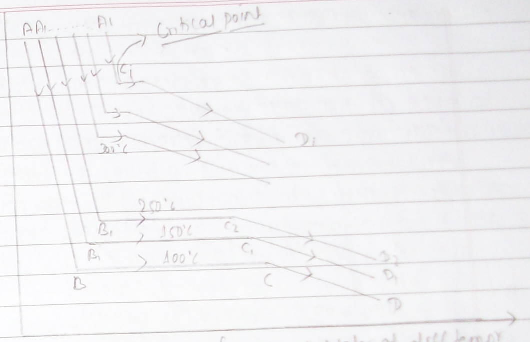


Fig: © P-v diagram for exp. of water at diff tempr

⇒ Now,
with reference to above fig. we can draw saturation curve and label different regions, lines and point as shown in fig ⓓ below

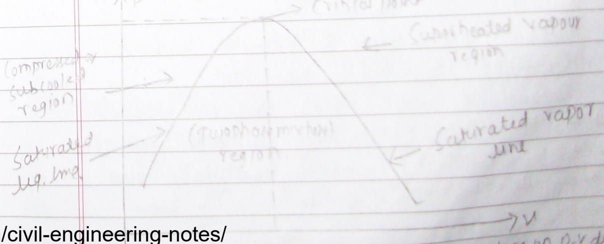
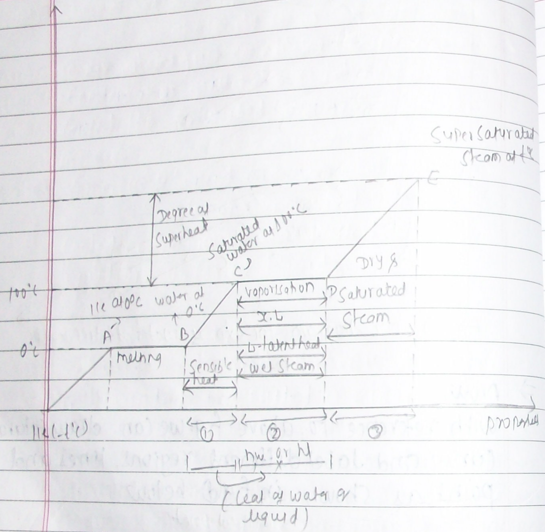


Fig: Saturation Curve for Two-phase mixture on P-v diagram



① -> Total heat of saturated water
② -> Total heat of wet steam.
③ Superheated steam.

↳ Heat of wet steam = $h_f + xL$
↳ Heat of Dry & Sat. Stem = $h_f + L$
↳ Heat of Supersaturated steam = $H_{saturated} + M c_p (T_{sup} - T_{sat})$

↗ mass of steam/vapour of initial water.

B.E

Imp # Terms used in Two-phase Mixture System:-

1.) Saturation Temperature :→

For a given pressure, the tempr at which phase change (liq to vapor or vapor to liquid) occurs is called a Saturation temperature.
For eg:- If we heat water at 1 atm, evaporation takes at 100°C, i.e Saturation temp for 1 atm is 100°C.

2) Saturation pressure :→

For a given tempr, the pressure at which the phase change occurs (liquid to vapor or vice-versa) is called a Saturation pressure. eg:- If we heat water at 100°C, evaporation takes at 1 atm pressure i.e Saturation pressure for 100°C tempr is 1 atm.

3) Saturated liquid :→

The state of a liquid at which the evaporation just starts (during heating) or condensation just completes (during cooling) is called Saturated liquid.

4) Saturated vapor :→

The state of a substance at which evaporation just completes (during heating) or condensation just starts (during cooling) is called the saturated vapor.

5) Compressed Liquid or sub cooled Liquid :→

When saturated liquid is further cooled or compressed, it is called a compressed liquid or sub cooled liquid.

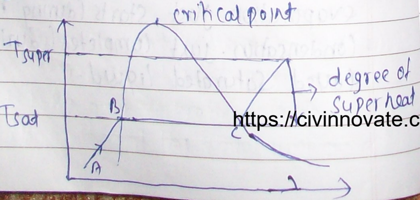
6) Superheat vapour :→

When saturated vapor is further heated or expanded, it is called a superheated vapor.

imp ⑦ Degree of Superheat :→

The difference in tempr of a superheated vapor and the corresponding saturation tempr is called degreee of superheat.

i.e.



imp 8) Critical point :→

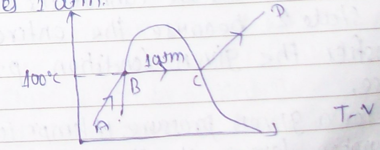
The state of a substance at which saturated liquid and vapor have identical properties is called a critical point. The pressure & tempr corresponding to critical point is called critical pressure & critical tempr.

For eg:- For H_2O, critical 'p' and 'T' are 22.055 MPa and 373°C. If we heat H_2O at 22.055 MPa it suddenly gets converted into saturated vapor from saturated liq. when tempr reaches 373°C. Therefore when a substance is heated at critical pressure, no phase transition is observed.

⊕ Properties of a two-phase mixture :→

Let us consider the saturation curve discussed previously on T-v diagram with a constant 'p' lines 1 atm.

i.e



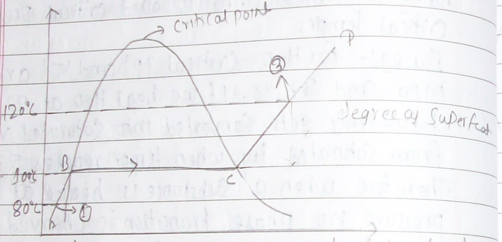
Now,

let us consider 3 states of H_2O as

State 1 : 1 atm, 80°C

State 2: 1 atm, 100°c
State 3: 1 atm, 120°c

To fix States on T-v diagram, we can add two Const. tempr lines on above fig. as.



Fg: locating States on T-v w.r.t Saturation lines

Now

Thus, we can fix State 1 as intersection of 80°c tempr line and 1 atm pressure line. and state 3 as intersection of 120°c tempr line and 1 atm pressure line. But we Cannot fix a unique line for State 2. because the entire line BC Satisfies the given Condition p = 1 & T = 100

Hence,

For a given pressure, if tempr is less than the Saturation tempr, its State will be a Compressed or Subcooled liq. and if tempr is higher than the Saturation tempr, the state will be a

Superheated Vapour.

Similary,

for p-v

We can shows a Saturation Curve on p-v diagram with a Const tempr line of 100°c

So let.

State 4: 1.2 atm, 100°c
State 5: 1 atm, 100°C
State 6: 0.8 atm, 100°c

Now, To fix these States on p-v diagram. we should add two Const pressure lines as below:

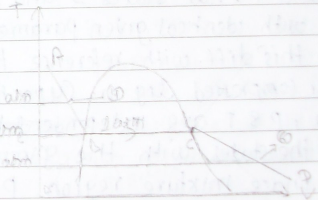


Fig: locating States on p-v w.r.t Saturated lines

Thus, State 4 can be fixed as intersection of 1.2 atm pressure line and 100°c tempr line and State 6 as intersection of 0.8 atm pressure line and [illegible] tempr line. Here again we cannot fix unique point for state 5; entire lines BC

Satisfies given condition of state 5.

↳ Hence, for a given T, if P is higher than Saturation pressure, its state will be a compressed or sub cooled liq and if P is less than Saturation 'p' state will be a Superheated vapour.

Quality :→ (Dryness fraction)

From the above examples, we can conclude that states 1, 3, 4 and 6 can be fixed with given 'p' and 'T'. But states 2 and 5 cannot be located with identical given parameters. We can compare this diff. with reference to state postulate. For compressed liq or Superheated vapor state, P & T are independent hence we can fix ~~two~~ the states with the given p and T. But for two phase mixture region, P & T are no more independent, and we cannot fix the state with dependent pressure and tempr.

To fix the state within the Saturation region we have to use a new property called quality. Thus,

Quality is defined as the ratio of mass of Saturated vapor and the total mass of the two phase mixture. It is also called dryness fraction. and is denoted by x.

i.e $\boxed{x = \frac{m_g}{m} = \frac{m_g}{m_l + m_g}}$

and;

m_g → mass of Saturated vapour.

m_l → mass of Saturated liquid.

m → total mass of two-phase mixture.

and;

↳ For saturated liquid state; $m = m_l$, $m_g = 0$

$\therefore x_{sat.liq} = 0$ ---- (i)

↳ For Saturated vapour state; $m = m_g$ or $m_l = 0$

$\therefore x_{sat.vap} = \frac{m_g}{m_g + m_l} = \frac{m_g}{m_g} = 1$

Hence, quality varies from 0 to 1 $(0 \le x \le 1)$ within the saturation region as below.

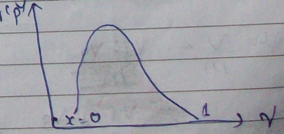


Fig: Limiting value of quality.

Moisture Content :→

To fix the state within the saturation region we can also use the propery Called moisture Content.

↳ moisture Content is defined as the ratio of mass of saturated liquid and the total mass of the two-phase mixture.

i.e $\boxed{y = \frac{m_l}{m} = \frac{m_l}{m_l + m_g}}$ — ②

Specific properties of a two phase mixture :-

⇒ Specific properties of a two phase system Can be expressed in terms of quality. For eg:- Specific volume of a two phase mixture is given by, ratio of total vol. of two-phase mixture & Total mass of two phase mixture

i.e

$$v = \frac{V}{m} = \frac{V_l + V_g}{m}$$

$$= \frac{V_l}{m} + \frac{V_g}{m}$$

→ V_l → vol. of saturated liquid.

→ V_g → vol. of Saturated gas (vapor)

So,

$$v = \frac{V_l \times m_l}{m_l \times m} + \frac{V_g \times m_g}{m_g \times m}$$

$$= \frac{V_l}{m_l} \times \left(1 - \frac{m_g}{m_g + m_l}\right) + \frac{V_g}{m_g}\left(\frac{m_g}{m_g + m_l}\right)$$

$$\boxed{\therefore\ v = v_l(1-x) + v_g x} \quad \text{— (i)}$$

x — drynes fraction.

where,

v_l = sp. vol. of Saturated liq.

v_g = sp. vol. of Saturated vapor.

or, $v = v_l(1-x) + v_g x$

or, $v = v_l + x(v_g - v_l)$

$$\boxed{v = v_l + x v_{lg}} \quad \text{— (ii)}$$

where,

$v_{lg} = v_g - v_l$ is change in sp. vol during evaporation.

Now,

↳ other sp. properties of two phase mixture can be expressed similary as,

↳ Specific internal energy, $\boxed{u = u_l + x u_{lg}}$ — (iii)

↳ " enthalpy , $\boxed{h = h_l + x h_{lg}}$ — (iv)

↳ " entropy $\boxed{s = s_l + x s_{lg}}$ — (v)

Enthalpy:-

$$H = U + PV \quad — (1)$$

So, $H_1 = U_1 + P_1V_1$

$H_2 = U_2 + P_2V_2$

$\therefore H_2 - H_1 = (U_2 - U_1) + (P_2V_2 - P_1V_1)$

$= M C_v (T_2 - T_1) + MR(T_2 - T_1)$

$= M(T_2 - T_1)(C_v + R)$

$= M(T_2 - T_1)(C_v + C_p - C_v)$

$\therefore \boxed{\Delta H = M C_p dt}$

change in enthalpy at always const p

Relationship between P and T & V & T during polytropic process:-

we know,

$P_1V_1^n = P_2V_2^n$ — (1)

$\left(\frac{V_1}{V_2}\right)^n = \left(\frac{P_2}{P_1}\right)$ — (1a)

$\left(\frac{V_1}{V_2}\right) = \left(\frac{P_2}{P_1}\right)^{1/n}$ — (1b)

Also,

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ — (2a)

or $\frac{V_1}{V_2} = \frac{P_2}{P_1} \times \frac{T_1}{T_2}$ — (2b)

Now, From eqn (1b) & (2b)

$\left(\frac{P_2}{P_1}\right)^{1/n} = \left(\frac{P_2}{P_1} \times \frac{T_1}{T_2}\right)$

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

Or, $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ — (3)

From (3) & (1a)

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n \times \frac{n-1}{n}}$

$\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}}$ — (4) (imp)

IOE question

1. Define pure substance. Explain why property tables and charts are necessary.

2. Define moisture content & critical point. Derive an expn for sp. vol of a two phase mixture interms of quality i.e $v = v_f + x v_{fg}$.

③ Define compressed liquid, degree of superheat, moisture content & saturated vapor.

④ Sketch the saturation curve of water in T-v with the help of isobar lines. Show all important points. lines and region. Also define saturation tempr & quality.

⑤ State & explain "state postulate"

⑥ State two property rule (State postulate) for a state Explain the importance of graphical and tabular data for steady state condn

⑦ Define compressed liq-line, sat-tempr and quality Derive $v = v_f + x v_{fg}$.

Chapter

First law of thermodynamics

Introduction:→

∴ first law of thermodynamics is based on the Conservation principles. it gives the mathematical expression for the effect of the ~~interaction~~ interaction between the system and sorrounding on the stored energy, (total) of the system.

Note:→

In Closed System (control mass), interactions can take place only in the form of energy transfer (work & heat). Therefore, first law of thermodynamics for a control mass can be explained with reference to Conservation of energy only. whereas.

In open system (control vol), interactions can take place both by mass as well as energy transfer, hence 1st law for a Control vol. Can be explained with reference to both Conservation of mass and energy.

∴ First law of thermodynamics for a Control mass :–

ie (1) Conservation of mass for control mass:→

⇒ only energy transfer takes place but not mass

So, $\boxed{dm = 0}$

or $\boxed{\frac{dm}{dt} = 0}$

② Conservation of energy for a control mass:→

Consider a control mass undergoing a process during which dQ amount of heat is supplied and it produces dw amount of work. If the heat supplied (Q) > work (w) then total energy increases, whereas if Q<w, then the total energy decreases.

i.e

we can generalize it as Conservation of energy for control mass as. The change in total energy of a Control mass is equal to heat supplied to control mass minus work produced by control mass

i.e.

$dE = dQ - dw$ — (i)

For any process between State 1 and 2

$E_2 - E_1 = Q_{12} - W_{12}$ — (ii)

but we know,

Total Energy $(E) = \overset{\nearrow \text{internal.}}{U} + P.E + K.E$ — (iii).

So, from (ii) & (iii)

$(U + P.E + K.E)_2 - (U + P.E + K.E)_1 = Q_{12} - W_{12}$

or, $(U + mgz + \frac{1}{2}mv^2)_2 - (U + mgz + \frac{1}{2}mv^2)_1 = Q_{12} - W_{12}$

Now,

For a Stationary piston cylinder device the change in P.E & K.E = 0 in comparision to change in internal energy.

∴ eqn (ii) becomes

$U_2 - U_1 = Q_{12} - W_{12}$

or, $\boxed{Q_{12} = (\Delta U)_{12} + W_{12}}$,

which is the relation for 1st law for control mass

Now,

For a Control mass undergoing cyclic process:→

Taking cyclic integration of eqn (i)

$\oint dE = \oint dQ - \oint dw$

but for a cyclic process, $\oint dE = 0$, so

we get

$\boxed{\oint dQ = \oint dw} \Rightarrow \boxed{\Sigma Q = \Sigma w}$

Hence,

First law of thermodynamics for a control mass undergoing a cyclic process can be stated as:-

During a cyclic process, there is no change in total energy of the system and therefore incoming energy should be equal to outgoing energy.

∴ Application of 1st law for non-flow process :→

(i) Const. vol (isochoric) process :→

$V = C$, So $W_{12} = 0$

so, we know, $dE = dQ - dw$ where $dw = 0$

$$\therefore \boxed{dQ = dE}$$

⇓

i.e heat transfered to a control mass during a const vol. process is equal to increase in internal energy.

(ii) Const. pressure (Isobaric) :-

For $P = C$

$W_{12} = P(V_2 - V_1)$, $P_1 = P_2 = P$

and we know

$dE = dQ - dw$

$dQ = dE + P(V_2 - V_1)$

$dQ = dE + P(V_2 - V_1)$

or, $dQ = (U_2 - U_1) + P_2V_2 - P_1V_1$ [∵ Total $E = U$ for Stationary cylinder

or, $dQ = (U_2 + P_2V_2) - (U_1 + P_1V_1)$

$$\therefore \boxed{dQ = h_2 - h_1 = \Delta h} \qquad \left(\because h \overset{\text{def}^n}{=} U + PV\right)$$

⇓

Change in enthalpy

(iii) Const. tempr (isothermal) :→

W_{12} at $T = C$, $= P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$

Then,

we know, $\Delta Q = dE + dw$ — ①

but for isothermal process

$du = mC_v dT = mC_v(T_2 - T_1) = 0$ — ⑪

So,

From ① & ⑪

$$\boxed{dQ = dw = P_1V_1 \ln \frac{V_2}{V_1}}$$

i.e heat transferred for a control mass consisting of an ideal during const. tempr is equal to work done by the system.

(iv) polytropic process :-

we know, $dQ = du + dw$ — (i)

but for polytropic

$du = mC_v(T_2 - T_1)$ — (ii)

$dw = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$ — ⓘⓘⓘ

Thus from ⓘ ⓘⓘ & ⓘⓘⓘ

$Q_{12} = mC_v(T_2 - T_1) + \frac{mR(T_2 - T_1)}{1-n}$

$Q_{12} = m\left(C_v + \frac{R}{1-n}\right)(T_2 - T_1)$

where

$\left(C_n = C_v + \frac{R}{1-n}\right)$ is polytropic Specific heat.

Specific heats of an Ideal gas:→

↳ Specific heat of a substance is defined as a heat required for raising tempr of a unit mass of Substance by 1°C. This is for solid & liquid.

But, for gas, heat required to raise tempr of unit mass of gas by 1°C is diff. for const. volume and constant 'p'.

∴ for a gas two Specific heats are defined i.e C_v & C_p.

Specific heat at constant volume:- (C_v)

as earlier at const. volume

$dw = 0$ so,

$\boxed{dQ = dy}$ — ①

Now, let us consider state postulate that specific internal energy of an ideal gas can be determined if its T and sp. volume are given i.e

$u = u(T, v)$ —(i)

Then,

change in Specific internal energy is given as

$$du = \left(\frac{dy}{dT}\right)_v dT + \left(\frac{du}{dv}\right)_T du \text{ — (ii)}$$

Now, for const vol; put $dv = 0$

so,

$$du = \left(\frac{du}{dT}\right)_v dT$$

or, $du = C_v dT$

$$\therefore \boxed{C_v = \left(\frac{du}{dT}\right)_v}$$

i.e defn:→ C_v is defined as the change in specific internal energy for per degree changer in tempr during a const vol.

* Specific heat at const. pressure:→

as, in C_v.

here, at const 'p', $dQ = dh$ - ①

So,

let $h = h(T, p)$ — (ii)

Then, $dh = \left(\frac{dh}{dT}\right)_p dT + \left(\frac{dh}{dp}\right)_T dp$

but $dp = 0$ so,

$$dh = \left(\frac{dh}{dT}\right)_p . dT$$

$\Rightarrow dh = C_p dT$ & $\boxed{C_p = \left(\frac{dh}{dT}\right)_p}$

all impmt for this page hand.

First law of thermodynamics for a Control volume :-

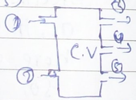
(1) Conservation of mass for a Control volume :→

→ Any Control volume (open system) Can interact with sorroundings by energy as well as mass transfer. In general, Conservation of mass for Control volume Can be Stated as: "The change in mass within a Control volume (C.V) is equal to mass entering into it minus mass leaving the Control volume."

i.e Mathematically

$$\frac{dm_{cv}}{dt} = m_{in} - m_{out} \quad —(i)$$

$$= (m_1 + m_2) - (m_3 + m_4 + m_5)$$



* Expression for mass flow rate :→

for both

⇒ Consider fluid flowing through a port Shown below having a uniform Cross Sectional area A, where it Crosses ΔL distance in time internal Δt

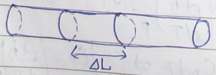


Fig: mass flow at a port

Then, mass of fluid crossing the ΔL is

$m = \rho V_{swept}$

or, $m = \rho(A.\Delta L)$

$\frac{dm}{dt} = \rho A \frac{\Delta L}{\Delta t}$

or, mass per time $= \rho A \bar{V}$ ($\bar{V}$ = velocity)

or, mass per time $= \frac{A\bar{V}}{v}$ (v = specific vol $= \frac{V}{m} = \frac{1}{\rho}$)

Thus, $\boxed{\frac{dm}{dt}_{C.V} = \sum_{in} \frac{A\bar{V}}{v} - \sum_{out} \frac{A\bar{V}}{v}}$ —(ii)

where, $\bar{V}$ = velocity, v = sp. volume $= \frac{1}{\rho}$

② Conservation of Energy for a Control volume :→

⇒ Along with heat transfer and work transfer, mass transfer also affects the total energy of a control volume. So, Conservation of energy for a Control volume Can be Stated as: "The Change in total energy of a C.V is equal to the net energy transported by fluid into the C.V plus the heat transferred to the C.V minus workdone by the C.V

i.e, mathematically

$$\frac{dE_{cv}}{dt} = E_{net} + Q - W$$

$$\frac{dE_{CV}}{dt} = (E_{in} - E_{out}) + Q - W \quad \text{— ①}$$

and $E_{in} = \sum_{in} \{ m(u + \frac{1}{2} \cancel{m} \bar{v}^2 + gz) \}$

where u = sp. internal energy.

and: $E_{out} = \sum_{out} \{ m(u + \frac{1}{2} \bar{v}^2 + gz) \}$ — ⓐ

↳ heat transfer always occurs due to diff. in temp between system & surrounding, whether it is a C.m or C.v

$Q = Q_{cv}$ — ⓑ

and but

The total work transfer is associated with a control volume (cv) includes various modes of work transfer such as flow work, shaft work, expansion/ compression work, etc., e

$W = W_{flow} + W_{shaft} + W_{general}$ — ⓒ

So from ①, ⓐ, ⓑ & ⓒ

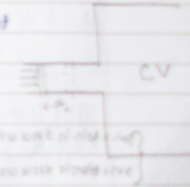
$$\boxed{\frac{dE_{CV}}{dt} = \sum_{in} \{ m(u + \tfrac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m(u + \tfrac{1}{2} \bar{v}^2 + gz) \} + Q_{cv} - W_{flow} - W_{shaft} - W_{general}}$$ — ①

Now;

Expression for flow work:-

flow work is the energy required to get the flowing fluid into the control volume or work performed by the fluid coming out from the control volume.

↳ Consider fluid flowing through an inlet section shown in fig. with a cross sectional area of A, where it crosses ΔL dist. in time interval Δt.



Energy (work) required for displacement is given by.

$W_{flow} = F \cdot \Delta L$

or, $W_{flow} = PA\Delta L$

$= P V_{swept}$

$\frac{W_{flow}}{time} = \frac{m \cdot P \cdot v_{swept}}{time}$ $(v = V/m)$

$\frac{W_{flow}}{time} = \dot{m}Pv$ $(m/t = \dot{m})$ — ②

From eq ① & ②

$$\frac{dE_{CV}}{dt} = \sum_{in} \{ m(u + \tfrac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m(u + \tfrac{1}{2} \bar{v}^2 + gh) \} + Q_{cv} + \sum_{in} (\dot{m}Pv) - \sum_{out} (\dot{m}Pv) - W_{cv}$$

i.e $$\frac{dE_{cv}}{dt} = \sum_{in}\left\{m\left(u+pv+\frac{1}{2}\bar{v}^2+gz\right)\right\} - \sum_{out}\left\{m\left(u+pv+\frac{1}{2}\bar{v}^2+gz\right)\right\} + Q_{cv} - W_{cv} \quad \text{— (III)}$$

but h(enthalpy) = u + pv

so,

eqn (III) becomes

$$\boxed{\frac{dE_{cv}}{dt} = \sum_{in}\left\{m\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\} - \sum_{out}\left\{m\left(h+\frac{1}{2}\bar{v}^2+gh\right)\right\} + Q_v - W_{cv}} \quad \text{— (IV)}$$

This is the general eqn for a C.V where express. $\left\{m\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\}$ represent energy.

Carried by the fluid and is called flow energy.

a

imp # Control volume (CV) Analysis :→

Analysis:- (i) with reference to spare (co-ordinate)

(a) uniform System:- properties of a system at a particular instant of time donot vary with spare (co-ordinate)

b) Non-uniform System :- vary.

(ii) with reference to time:-

(a) steady:- properties donot vary with time at a particular instant.

(b) unsteady state system:- vary.

imp (a) Steady State Analysis:- (for C.V)

Here,

we know from previously done mass conservation

$$\frac{dm_{cv}}{dt} = \bar{m}_{in} - \bar{m}_{out} \quad \text{— (i)}$$

and $$\frac{dE_{cv}}{dt} = \sum_{in}\left\{m\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\} - \sum_{out}\left\{\bar{m}\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\} + \bar{Q}_{cv} - \bar{W}_{cv} \quad \text{— (II)}$$

but, for the steady state operation of a control volume, its properties (i.e total mass & energy) shouldnot change with time so, we can say, $\left(\frac{dm}{dt}\right)_{cv} = 0$

and $\left(\frac{dE}{dt}\right)_{cv} = 0$

Thus, eqn (I) & (II) reduces to

$0 = \bar{m}_{in} - \bar{m}_{out}$

i.e $\boxed{\bar{m}_{in} = \bar{m}_{out}}$ —(III)

and,

$$0 = \sum_{in}\left\{\bar{m}\left(h + \frac{1}{2}\bar{V}^2 + gz\right)\right\} - \sum_{out}\left\{\bar{m}\left(h + \frac{1}{2}\bar{V}^2 + gz\right)\right\} + \bar{Q}_{cv} - \bar{W}_{cv}$$

i.e $$\boxed{\sum_{in}\left\{\bar{m}\left(h + \frac{1}{2}\bar{V}^2 + gz\right)\right\} + \bar{Q}_{cv} = \sum_{out}\left\{\bar{m}\left(h + \frac{1}{2}\bar{V}^2 + gz\right)\right\} + \bar{W}_{cv}}$$ —(IV)

Thus,
eqn (III) & (IV) says that for the steady state operation, incoming mass should be equal to outgoing mass & incoming energy should be equal to outgoing energy.
and,

Most common examples of steady state devices are turbine, compressor, nozzle etc. These devices have single inlet and single outlet.

i.e

$\bar{m}_1 = \bar{m}_{in}$

$\bar{m}_2 = \bar{m}_{out}$

i.e $\bar{m}_1 = \bar{m}_2 = \bar{m}$ (from (III))

and

from (IV)

$$\bar{m}_1\left(h_1 + \frac{1}{2}\bar{V}_1^2 + gz_1\right) + \bar{Q}_{cv} = \bar{m}_2\left(h_2 + \frac{1}{2}\bar{V}_2^2 + gz_2\right) + \bar{W}_{cv}$$

i.e $$\boxed{\bar{Q}_{cv} - \bar{W}_{cv} = \bar{m}\left[(h_2 - h_1) + \frac{1}{2}(\bar{V}_2^2 - V_1^2) + g(z_1 - z_2)\right]}$$ (a)

is reqd final expn for steady state analysis.

(b) unsteady State Analysis :—

But,

During unsteady state analysis, its properties (total mass and total energy) change with time i.e total mass and total energy are function of time.

i.e $\frac{dm_{cv}}{dt} \neq 0$ i.e $m_{cv} = f_1(t)$ —(i)

And $\frac{dE}{dt} \neq 0$ i.e $E_{cv} = f_2(t)$ —(ii)

∴ the generalized mass conservn and energy conservation for the unsteady state devices can be derived by integrating eqn

$$\int_{t_1}^{t_2}\left(\frac{dm_{cv}}{dt}\right)dt = \int_{t_1}^{t_2}\bar{m}_{in}\,dt - \int_{t_1}^{t_2}\bar{m}_{out}\,dt$$

$$\therefore \boxed{(m_2 - m_1) = m_{in} - m_{out}}$$

where m_1 & m_2 are masses of C.V at state 1 and state 2. m_{in} is total mass entered, m_{out} is total mass gone out from CV during the interval t_1 to t_2

Similary,

Integrating energy conservation eqn we get.

$$\int_{t_1}^{t_2}\left(\frac{dE_{cv}}{dt}\right)dt = \int_{t_1}^{t_2}\sum_{in}\left\{m\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\}dt$$

$$-\int_{t_1}^{t_2}\sum_{m_{out}}\left\{m\left(h+\frac{1}{2}\bar{v}^2+gz\right)\right\}dt$$

$$+\int_{t_1}^{t_2}Q_{cv}\,dt - \int_{t_1}^{t_2}W$$ [illegible]

$$\boxed{\begin{aligned}\therefore (E_{cv})_2-(E_{cv})_1 = {} & m_{in}\left(h_{in}+\frac{1}{2}\bar{v}_{in}^2+gz_{in}\right)\\ & -m_{out}\left(h_{out}+\frac{1}{2}\bar{v}_{out}^2+gz_{out}\right)\\ & +Q_{1-2}-W_{1-2}\end{aligned}}$$

where, h_{in} is sp. enthalpy of the in coming fluid. V_{in} is the velocity of inclimbing fluid. Z_{in} is evaction of inlet section from the reference level

Imp # Control volume Applications:→

⇒ Depending upon their operation and function, common control volume applications can be classified into four groups:-

(i) Steady state work application.
(ii) Steady state flow application.
(iii) unsteady state work application.
(iv) unsteady state ~~work~~ flow application

defn!: ① Steady state work Application:→

The devices which operate under steadly state conditions and either produce or consume work are called Steady State work applications.

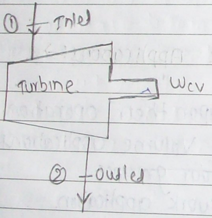
Eg:- turbine, compressor, pump, fan etc.

↳ A turbine is a device which produces power or work by consuming energy carried by a fluid. A turbine has generally a single inlet and a single outlet.

∴ Energy eqn for steady state operation of turbine is given by,

$$\boxed{\bar{Q}_{cv} - \bar{W}_{cv} = m\left[(h_2-h_1) + \frac{1}{2}(\bar{V}_2^2-\bar{V}_1^2) + g(z_2-z_1)\right]}$$

i.e — ①

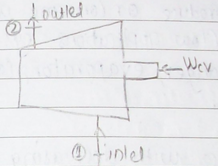


→ If the turbine surface is insulated and heat transfer loss is negligible, it is called an adiabatic turbine. Therefore, for a adiabatic turbine energy eqn reduces to:-

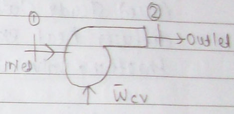
$$\boxed{\frac{dW_{cv}}{dt} = m\left[(h_1-h_2) + \frac{1}{2}(\bar{V}_1^2-\bar{V}_2^2) + g(z_1-z_2)\right]}$$

— (II)

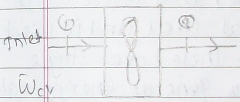
↳ Compressor, pump and fan increase fluid energy by consuming mechanical work. Schematic representations of three devices are shown in fig below:-



Compressor



pump



Fan.

→ Compressor usually increases pressure energy of the gaseous substance, pump increases pressure or P.E. of liquid substance and fan increase K.E of fluid. Hence energy eqn for those are same as above ① and if these operates under adiabatic condition then eqn as (II)

② Steady State flow Applications:-

For these also $W_{cv} = 0$ always.

Defn:-

Devices which operate under steady state condition but donot produce or consume work are called steady state flow applications. eg:- nozzle, diffuser, heat exchanger, evaporator, condenser, throttling valve etc.

↳ Nozzle is a device with decreasing cross-sectional area and is used to increase fluid velocity whereas diffuser is a device with increasing cross sectional area and is used to decrease fluid velocity. These have single inlet and single outlet so, general energy eqn for these devices is given as:-

$$\boxed{\dot{Q}_{cv} = \dot{m}\left[(h_2-h_1)+\frac{1}{2}(\bar{V}_2^2-\bar{V}_1^2)+g(z_2-z_1)\right]}$$

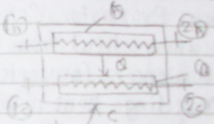
in these devices, change in P.E is usually negligible in comparision to change in K.E. or change in enthalpy. If the nozzle or diffuse is operating under adiabatic condition, energy eqn reduces to;

$\frac{dQ_{cv}}{dt} = 0$; so

$$(h_2-h_1)+\frac{1}{2}(\bar{V}_2^2-\bar{V}_1^2) = 0$$

$$\boxed{h_1+\frac{\bar{V}_1^2}{2} = h_2+\frac{\bar{V}_2^2}{2}}$$

↳ Heat exchanger is a device used to transfer heat from one fluid to another.



Eg: heat exchanger

where,

1_h = inlet of hot fluid
2_h = outlet of hot fluid
1_c = inlet of cold fluid
2_c = outlet of cold fluid
Q = mag. of net heat exchange.

In heat exchanger ΔPE and K.E are negligible in comparison to change in enthalpy (Δh) so, energy eqn for control volume 'A' is

$$\boxed{\frac{dQ}{dt} = \underset{\text{hot}}{\underset{\downarrow}{\dot{m}_h}}(h_{2h}-h_{1h})}$$

and

Similarly, for control volume 'c' is

$$\boxed{\bar{m}_h . h_{1h} + \vec{m}_c h_{1c} = \vec{m}_h h_{2c} + \bar{m}_c h_{2c}}$$

m_c = mass flow rate of cold fluid,

↳ Evaporator and Condenser are special types of heat exchangers. Evaporator converts liquid into vapor by absorbing heat from the sorroundings whereas condenser converts vapor into liquid by rejecting heat to the sorrounding. So, their energy flow is.

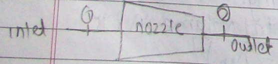
$$\vec{Q} = \bar{m}(h_2 - h_1)$$

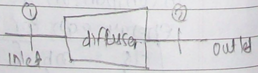
↳ Throttling valve reduces the pressure of fluid without performing work.

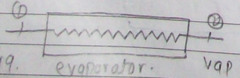
energy eqn as, $h_2 - h_1 = 0$

$$\boxed{h_2 = h_1}$$

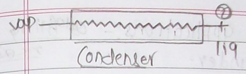
fig! -



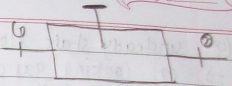




evaporator.



Condenser



Throttling valve

③ unsteady State work applications:-

→ Turbine, compressor, pump etc operate at steady state at their normal operations but the same devices operate at unsteady state during the start-up and shut-down period.

The eqn are:

$$m_2 - m_1 = m_{in}.$$

$$(E_{cv})_2 - (E_{cv})_1 = m_{in}(h_{in} + \frac{1}{2}\bar{V}_{in}^2 + g z_{in}) + Q_{12} - W_{12}$$

and ΔP.E & ΔKE is negligible to change in internal energy so.

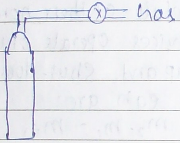
eqn is:-

$$m_2 u_2 - m_1 u_1 = m_{in}(h_{in} + \frac{1}{2}V_{in}^2 + g z_{in}) + Q_{12} - W_{12}$$

(vvI) (4) unsteady state flow applications:- ~~as~~ filling process read

⇒ eg: Cooking gas cylinder.

During cooking, gas is consumed and mass of system continuously decreases and it does not produce any boundary work. It is an unsteady state flow application.



The eqn are

$m_2 - m_1 = -m_{out}$ -ve indicate decrease in mass.

$(E_{cv})_2 - (E_{cv})_1 = -m_{out}\{h_{out} + \frac{1}{2}V_{out}^2 + gz_{out}) + Q_{1-2}$

$\therefore W_{1-2} = 0$ (C.V).

#) other statements of 1st law:-

(a) 1st law for an isolated system:-

$dE = dQ - dW$

For control mass isolated system, $dQ = dW = 0$

So, $dE = 0$

i.e $E_2 - E_1 = 0$

i.e $E_2 = E_1$

(b) 1st law for CM undergoing adiabatic process:

⇒ For isolated, $dQ = 0$

$\boxed{dE = -dW}$

(c) Perpetual motion machine of 1st kind (PMM-I) is not possible:-

Chapter-5

Second law of thermodynamic

Limitations of the first law (Necessity of 2nd law)

⇒ 1st law of thermodynamics explains thermodynamic process with reference to mass conservation and energy conservation. it deals with the quantitative aspect of the energy and gives the only condn that any process is possible provided that the total energy remains const. But, some process in nature canot occur although energy conservation principle is satisfied. In this regard, the second law of thermodynamics deals with quality or nature of energy & defines the direction of the process in which system can proceed.

The following examples gives idea about the limitations of 1st law:—

ⓐ According to 1st law, for a cyclic process $\oint dQ = \oint dW$ But any real device cannot convert heat supplied to output work completely. i.e hence, 2nd law explains why any real engine cannot operate without heat loss.

ⓑ 1st law of thermodynamics says about the flow of heat but it has failed to show the direction of heat flow that it occurs from high tempr to low tempr.

VVI
B.E [6]

(Q) Explain the directional feature of the natural process with one example. State the Second law of thermodynamics for an isolated system. Explain the entropy generation.

⇒ The directional feature of the natural process is that most of the process in nature proceed in only one direction. which can be explained by 2nd law of thermodynamics. The 2nd law defines the directon of the process with reference to the system property. Called entropy. Thus, it says that, the system (nature process) itself tends to undergo a process from less uncertain or randomness or entropy to more entropy or randomness. But the reverse is not possible.

For example:-

Consider an insulated container having two compartments as shown in fig. below (State 1)

Due to the pressure difference between the two compartments. gas continuously exerts force on the partition wall. If the gas pressure is sufficient to break the partition wall, gas expands and fills up the entire container as in figure. (State 2)

If we analyse the process 1-2, total energy is

Same for both State 1 & 2. But if we assume the reverse direction i.e 2 to 1, 1st law is still Satisfied (E = const) but system can never proced in this direction.

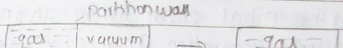


fig: possible direction

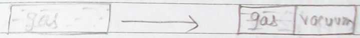


fig: impossible direction

2nd law of thermodynamics for an isolated system:-

An isolated system is that system where the loss or gain of heat through the system is zero. As we know that, any isolated system can proceed in the direction in which its randomness or uncertainity i.e entropy increases. Thus, we can state 2nd law of thermodynamics for an isolated system is:-

"Entropy of an isolated system always increases or may remain const (for an ideal process)"

i.e Mathematically,

$(dS)_{isolated} \geq 0$ —(i)

or $S_{final} - S_{initial} \geq 0$

$\boxed{S_{final} \geq S_{initial}}$ —(ii)

This eqn shows that entropy of an isolated System at the final State in any real process is always greater than that at the initial State and.

The diff. between entropies at the final State and the initial State during any process is called entropy generation and is denoted by δS_{gen}.

Thus,

$$(\delta S_{gen})_{isolated} \geq 0$$

also, $\left(\frac{dS}{dt}\right)_{isolated} \geq 0$

or $\frac{dS_{gen}}{dt} = S_{gen} \geq 0$ — (iii)

Reversible and Irreversible process:→

According to 2nd law of thermodynamics, during any real process net entropy change is always ≥ 0.

i.e $S_2 \geq S_1$ – (i)

↳ During $S_2 = S_1$, the reverse process is also possible as entropy is same for both forward & backward directions and thus it is reversible.

but if $S_2 > S_1$, the reverse is not possible because

any real process cannot result in decrease in entropy. and hence it is irreversible process.

Defn:-

↳ A process is said to be reversible if the initial conditions of both the system and surrounding can be restored by the reverse action such that net entropy change is zero for both forward & reverse process.

↳ A process is said to be irreversible, if the initial condn of both the system & surrounding cannot be restored by reverse action.

↳ A process is said to be an internally reversible if the initial condn of only the system is restored when the system is taken through reverse direction.

↳ Similarly, a process is said to be an externally reversible if the initial condn of only the surrounding is restored when the system is taken through reverse direction.

Therefore, for a process to be a complete reversible process, it should be internally as well as externally reversible.

Note:- Most of the real processes in nature are irreversible and we can model those processes as reversible process with certain Simflifying assumption as:-

- ↳ Assuming surface to be frictionless
- ↳ Assuming deformation during non-linear spring with elastic range.
- ↳ Assuming heat transfer with small finite tempr difference. etc.

B.E

(Q) Explain entropy. Derive the relations for entropy for an ideal gas and an incompressible substance.

⇒ An entropy is the thermodynamics property which gives the measurement of degree of randomness. An entropy increases with increase in temperature as randomness increases. It can be used with any other property to describe the state of a system.

Now,

Applying state postulate, we can determine the internal energy of a system if its volume and entropy, are given as:—

$$U = U(S, V) \text{ — (i)}$$

Thus, change in internal energy is given as,

$$\boxed{dU = \left(\frac{\partial U}{\partial S}\right)_V dS + \left(\frac{\partial U}{\partial V}\right)_S dV} \text{ — ⓘⓘ}$$

Now,

The two partial derivatives in above eqn are the ratio of two extensive properties hence are the ratio of two extensive properties, hence are intensive parameters. i.e The first partial derivative is tempr and second is -ve of pressure.

i.e $T = \left(\frac{\partial U}{\partial S}\right)_V$ and $P = -\left(\frac{\partial U}{\partial V}\right)_S$

Thus, eqn (ii) becomes,

$$\boxed{dU = TdS - PdV}$$

i.e

which is gibb's eqn. now

$$TdS = dU + PdV$$

$$\text{or} \quad \boxed{dS = \frac{dU}{T} + \frac{P}{T}dV} \text{ — (iii)}$$

also,

Acc to defn of enthalpy,

$$H = U + PV$$

So, change in enthalpy is given by diff it as

$$\boxed{dH = dU + PdV + VdP} \text{ — (iv)}$$

or,

$dH = Tds - pdv + pdv + vdp$ $(\because du = Tds - pdv)$

or, $dH = Tds + vdp$

$\therefore \boxed{ds = \frac{dH}{T} - \frac{V dP}{T}}$ —— ⓥ

Now,

For an ideal gas:-

we know,

$pv = mRT$ $(R \rightarrow J/kgK)$

or, $\frac{P}{T} = \frac{mR}{V}$

and, For an ideal gas, $dU = mC_v dT$

Thus, the eqn (iii) becomes,

$$ds = \frac{mC_v dT}{T} + mR\frac{dv}{V}$$

Now, Assuming Cv and R const. integrating above eqn from State 1 to 2.

$$\int_{S_1}^{S_2} ds = mC_v \int_{T_1}^{T_2} \frac{dT}{T} + mR \int_{V_1}^{V_2} \frac{dV}{V}$$

or, $\boxed{S_2 - S_1 = mC_v \ln\left(\frac{T_2}{T_1}\right) + mR \ln\left(\frac{V_2}{V_1}\right)}$ —(vi)

also,

$pv = mRT$

$\frac{V}{T} = \frac{mR}{P}$

and, Change in enthalpy of an ideal gas is given by

$dH = mC_p dT$

So, the eqn ⓥ becomes,

$$ds = \frac{mC_p dT}{T} - \frac{mR dp}{P}$$

Now, assuming Cp and R as Const. integrating above eqn from State 1 to State 2:

$$\int_{S_1}^{S_2} ds = mC_p \int_{T_1}^{T_2} \frac{dT}{T} - mR \int_{P_1}^{P_2} \frac{dP}{P}$$

$\boxed{S_2 - S_1 = mC_p \ln\left(\frac{T_2}{T_1}\right) - mR \ln\left(\frac{P_2}{P_1}\right)}$ ← (vii)

Thus,

eqn (vi) & (vii) are the eqn for entropy change for an ideal gas.

* For incompressible Substance:-

Solid and liquid Substances are considered as incompressible as their volume dont change i.e $dv = 0$ with the pressure or Temperature

Thus,

eqn (iii) becomes

$$ds = \frac{dU}{T} + \frac{P}{T} \times 0$$

$$= \frac{dU}{T} = \frac{mcdT}{T} \quad (dU = mcdT)$$

C = sp. heat of incompressible substance

on integration.

$$\boxed{S_2 - S_1 = mc \ln\left(\frac{T_2}{T_1}\right)}$$

Control mass formulation of 2nd law of thermodynamics:-

or,

Q Derive the expn of entropy generation for control mass (C.M)

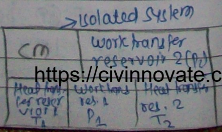
⇒ As we know that any control mass (C.M) can interact with its sorrounding either by heat transfer or by work transfer, the CM formulation of 2nd law gives the expression for change in entropy (ds) of CM due to

(i) heat transfer.

(ii) work transfer.

Now,

Consider an isolated system as below consisting of a CM interacting with a no. of heat transfer reservoirs and work transfer reservoir.



(i) By Heat transfer:→

Consider a system having infinite heat capacity such that its tempr is unaffected by the heat transfer. Such an idealized system which can interact with its sorroundings only by heat transfer (but not work transfer) [$dQ = m c dt$] is called a reversible heat transfer reservoir and is specified by its tempr (T_i).

Now,

as, here, work transfer is zero. ($dw = 0$)

and we know,

$$ds = \frac{du}{T} + \frac{Pdv}{T_i}$$

$$\therefore\ ds = \frac{u}{T_i} + 0 = \frac{du}{T_i} \quad \text{— (1)}$$

and, from 1st law,

$$dQ = du + dw = du + 0$$

$$\therefore\ du = dQ$$

So eqn (i) becomes

$$\boxed{ds = \frac{dQ}{T_i}} \quad \text{— (2)}$$

This eqn shows that entropy of a system increases if heat is supplied to it and decreases if it loses heat.

VVI.

(ii) By work transfer:-

Consider a system having infinite work capacity such that its pressure is unaffected by the work transfer. Such an idealized system which can interact with its sorrounding only by the work transfer (not by heat) is called a reversible work transfer reservoir and is specificed by its pressure (P_i).

Now,

From 1st law for reversible work transfer reservoir

$$dQ(=0) = du + dw$$

$$= du + Pdv$$

$$\text{or, } du = -Pdv \quad — ①$$

and as we know $ds = \frac{du}{T} + \frac{Pdv}{T}$

$$\therefore (ds)_{WTRs} = -\frac{PdV}{T} + \frac{PdV}{T}$$

$$\therefore \boxed{ds = 0} \quad —(ii)$$

This shows that work transfer doesnot have any contribution on the entropy of the system.

Now,

Accn to 2nd law of thermodynamics for isolated system, $(ds)_{isolated} \geq 0$

and as total change in entropy is given by ds of reversible heat transfer reserviors, reversible work transfer reservoir and ds of control mass (CM)

So,

we have, $(ds)_{cm} + \Sigma(ds)_{RHTRs} + \Sigma(ds)_{RWTRs} \geq 0$ —(iii)

but from (ii), ds of work transfer reservoir is zero

So, we get,

$$(ds)_{cm} + \Sigma(ds)_{RHTRs} \geq 0 \quad — (iv)$$

and,

from, as ds for Heat transfer reservoirs,

$$(ds) = \frac{dQ}{T}$$

$$\therefore (ds)_{RHTRs} = \Sigma\left(\frac{dQ_i}{T_i}\right)_{RHTS}$$

So, eqn (iv) becomes,

$$(ds)_{cm} + \Sigma\left(\frac{dQ_i}{T_i}\right)_{RHTRs} \geq 0$$

but $(dQ_i)_{RHTRs}$ is the heat supplied to reservior at tempr T_i, that is supplied by CM

$$\therefore (dQ_i)_{RHTRs} = -(dQ_i)_{cm}$$

So that above eqn become

$$(ds)_{cm} - \Sigma\left(\frac{dQ_i}{T_i}\right)_{cm} \geq 0$$

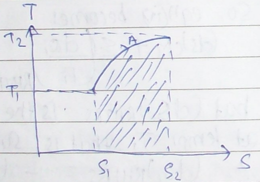
$$\text{Or, } \boxed{(ds)_{cm} \geq \Sigma\left(\frac{dQ_i}{T_i}\right)_{cm}} \quad — (v)$$

Thus,
Acc to eqn (v), The 2nd law of thermodynamics for CM formulate can be stated as:-
"The change in entropy of a CM is greater than or equal to the sum of heat transfers divided by corresponding boundary absolute tempr"
and thus, for a single reservoir undergoing reversible process, eqn (v) reduces to

$$ds = \frac{dQ}{T}$$

$$\therefore \boxed{dQ = Tds}$$

Thus, area under T-S diagram gives the mag. of heat transfer as.



also, in term of entropy generation:

$$(ds)_{cm} - \Sigma\left(\frac{dQ_i}{T_1}\right)_{cm} = (ds)_{gen} \geq 0$$

$$(\delta s)_{gen} = (ds)_{cm} - \Sigma\left(\frac{dQ_i}{T_i}\right)_{cm}$$

also in term of rate

$$\left(\frac{ds}{dt}\right)_{cm} \geq \Sigma\left(\frac{Q_i}{T_i}\right)_{cm} \quad / \quad \left(\frac{ds}{dt}\right)_{cm} - \Sigma\left(\frac{Q_i}{T_i}\right)_{cm} = S_{gen}$$

BE

Control vol. formulation of 2nd law:-

or,

* State the entropy change statement for control volume and derive an expn for its entropy generation.

⇒ CV formulation of 2nd law gives the eqn for entropy change of a cv due to mass transfer as well as energy transfer. The effect of mass transfer on the entropy can be determined by evaluating properties of working substance at inlet & outlet. The effect of heat and work transfer on entropy of cv is same as for CM.

$\therefore$ we can state 2nd law of thermodynamics for CV as,
"The change in entropy of a Control Volume minus the net entropy change of working substance due to mass transfer is greater than or equal to the ~~con~~ corresponding sum of heat transfer divided by corresponding boundary absolute temperatures."

i.e Mathematically,

$$(ds)_{cv} - ds_{net} \geq \Sigma\left(\frac{Q_i}{T_i}\right)_{cv}$$

expressing in rate (per time)

$$\left(\frac{ds}{dt}\right)_{cv} - \dot{S}_{net} \geq \Sigma\left(\frac{\dot{Q}_i}{T_i}\right)_{cv}$$

or, $$\boxed{\left(\frac{ds}{dt}\right)_{cv} - \dot{S}_{in} + \dot{S}_{out} \geq \Sigma\left(\frac{\dot{Q}_i}{T_i}\right)_{cv}} \quad -(i)$$

$(\because \dot{S}_{net} = \dot{S}_{in} - \dot{S}_{out})$

Now,
eqn① can be expressed in terms of entropy generation to avoid inequality as:

$$\left(\frac{ds}{dt}\right)_{cv} - \dot{S}_{in} + \dot{S}_{out} - \Sigma\left(\frac{\dot{Q}_i}{T_i}\right)_{cv} - \dot{S}_{gen} = 0$$

where $$\boxed{\dot{S}_{gen} = \left(\frac{ds}{dt}\right)_{cv} - \dot{S}_{in} + \dot{S}_{out} - \Sigma\left(\frac{\dot{Q}_i}{T_i}\right)_{cv}}$$

B.Q./ Define isentropic process. Derive relations for an ideal gas and an incompressible substance.

⇒ The change in entropy of any system during a reversible process is given by

$$ds = \frac{dQ}{T}$$

↳ If the process is reversible as well as adiabatic $dQ = 0$, so, eqn reduces to

$$ds = 0$$

i.e, $S_2 - S_1 = 0$

$\therefore S_2 = S_1$

Defn Hence, during a reversible and adiabatic process, entropy of the system remains const. and the process is called an isentropic process.

* Isentropic relations for an ideal gas.

We know,

The entropy relations for an ideal gases are

$$S_2 - S_1 = mc_v \ln\left(\frac{T_2}{T_1}\right) + mR\ln\left(\frac{V_2}{V_1}\right) \quad -①$$

and $$S_2 - S_1 = mc_p \ln(T_2/T_1) - mR\ln\left(\frac{P_2}{P_1}\right) \quad -②$$

Now,

In eqn① putting $S_2 - S_1 = 0$ for isentropic process we get,

$$0 = mc_v \ln(T_2/T_1) + mR\ln(V_2/V_1)$$

or, $$mc_v \ln\left(\frac{T_2}{T_1}\right) = -mR\ln\left(\frac{V_2}{V_1}\right)$$

or, $$\ln\left(\frac{T_2}{T_1}\right)^{c_v} = \ln\left(\frac{V_2}{V_1}\right)^{-R}$$

or, Taking anti-log

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

or, $$\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{R/c_v} = \left(\frac{V_1}{V_2}\right)^{\frac{c_p-c_v}{c_v}} \qquad (\because R = c_p - c_v)$$

or, $$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\frac{c_p}{c_v}-1}$$

or, $$\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}}$$ which is the real isentropic relation.

Again, In eqn (ii) putting $S_2 - S_1 = 0$ for isentropic process; we get.

$$0 = mc_p \ln\left(\frac{T_2}{T_1}\right) - mR\ln\left(P_2/P_1\right)$$

or, $$mc_p\ln\left(T_2/T_1\right) = mR\ln\left[P_2/P_1\right]$$

or, $$\ln\left(\frac{T_2}{T_1}\right)^{c_p} = \ln\left(\frac{P_2}{P_1}\right)^{R}$$

Taking anti-log.

or, $$\left(\frac{T_2}{T_1}\right)^{c_p} = \left(\frac{P_2}{P_1}\right)^{R}$$

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{R/c_p}$$

or, $$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{c_p-c_v}{c_p}}$$

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

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

which also the isentropic reln between T-P for an ideal gas undergoing an isentropic process.

✽ Isentropic relation for an incompressible Substance:-

Here,

The change in sp. entropy of an incompressible substance is given by $ds = \frac{du}{T}$ — (i)

but $ds = 0$ for isentropic process.

So, for (i) we get.

$$ds = \frac{du}{T} = 0.$$

or, $du = 0$ — (ii)

Now, we know

$h = u + pv$

$\therefore dh = du + pdv + vdp$ — (iii)

from (ii) & (iii)

$dh = 0 + p\overset{\text{sp-vol. change}}{dv} + vdp$ — (iv)

but for incompressible substance, $dv = 0$

So, eqn (iv) becomes

$dh = vdp$

on integration for process 1-2

$$(h_2 - h_1) = v(P_2 - P_1)$$

which is the required isentropic relation for incompresible substances.

Isentropic Efficienty of Steady flow devices:-

ⓐ Turbine:-

In case of work producing device, real work is always less than isentropic work output, because of losses. Hence, isentropic relation for Turbine is,

$$\boxed{\eta_{IT} = \frac{W_{real}}{W_{isen}}}, \quad IT \rightarrow \text{Isentropic turbine.}$$

ⓑ pump/compressor:-

In case of work consuming devices real work is always > isentropic work input ∵ we have to increase work input to overcome the loses to get some desired output effect so,

$$\boxed{\eta_{IP}, \eta_{IC} = \frac{W_{isen}}{W_{real}}}$$

ⓒ Isentropic Efficiency of a nozzle:-

It is ratio of K.E of fluid at real nozzle exist to K.E value at exit of an isentropic nozzle for same inlet state and exit pressure,

so,

$$\eta_{IN} = \frac{(\bar{V}_{real})^2/2}{(\bar{V}_{isen})^2/2} = \frac{(\bar{V}_{real})^2}{(\bar{V}_{isen})^2}$$

Calculate the change in entropy if

ⓐ P = constant:-

$$ds = \frac{dQ}{T} = \frac{mC_p dT}{T} \quad (\text{at const } P, \; dQ = mC_p dT)$$

on integration.

$$\boxed{S_2 - S_1 = mC_p \ln(T_2/T_1)}$$

ⓑ V = constant:-

$$dQ = mC_v dT$$

$$\text{so, } ds = \frac{dQ}{T} = \frac{mC_v dT}{T}$$

∴ on integration,

$$\boxed{S_2 - S_1 = mC_v \ln(T_2/T_1)}$$

ⓒ $pv = T =$ const (isothermal)

$$dQ = \overset{0}{du} + dw = P_1 v_1 \ln v_2/v_1$$
$$= mRT \ln(v_2/v_1)$$

$$\therefore ds = \frac{dQ}{T} = \frac{mRT \ln v_2/v_1}{T}$$

$$\boxed{S_2 - S_1 = mR \ln v_2/v_1}$$

ⓓ $pv^{\gamma} = c$ (adiabatic) :-

$$dQ = 0$$
$$ds = \frac{dQ}{T} = 0$$
$$S_2 - S_1 = 0 \Rightarrow \boxed{S_2 = S_1}$$

ⓔ $pv^n =$ const

$$dQ = du + dw$$
$$= mC_v dT + \frac{P_1 v_1 - P_2 v_2}{n-1}$$
$$= \frac{P_1 v_1 - P_2 v_2}{n-1}\left[\frac{\gamma - n}{\gamma - 1}\right]$$

$$\therefore ds = \frac{dQ}{T} = \frac{\gamma - n}{\gamma - 1} \cdot \frac{W}{T}$$
$$= \frac{\gamma - n}{\gamma - 1} \cdot \frac{pdv}{T}$$
$$= \frac{\gamma - n}{\gamma - 1} \cdot \frac{mRT dv}{T \cdot v}$$

On integration

$$\boxed{S_2 - S_1 = \frac{\gamma - n}{\gamma - 1} \cdot mR \ln v_2/v_1}$$

Carnot - Cycle :→

↳ It is an ideal devised by Carnot which will have efficiency equal to that of a reversible cycle (theoretical maximum) without considering its mechanical details, not practically possible.

It consists of following process as figure(graph) i.e

process 1-2 : Isothermal heat addition.
process 2-3 : Isentropic expansion.
process 3-4 : Isothermal heat rejection.
process 4-1 : Isentropic compression.

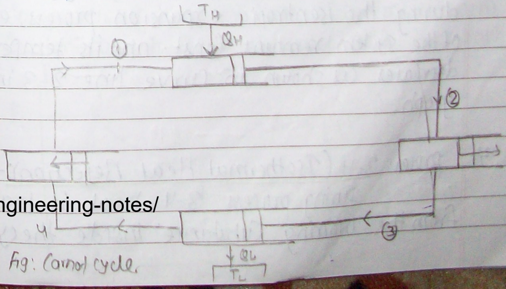


Fig: Carnot cycle.

* process 1-2 [Isothermal Heat addition]:-

During process 1-2, heat is added to the working substance inside the cylinder from a high temperature source having a temperature T_H and the working substance undergoes an isothermal expansion; during which pressure decreases, its volume increases, its tempr remains ~~cst~~ const and the entropy increases as shown by line 1-2 in graph.

* process 2-3 [Isentropic Expansion]:→

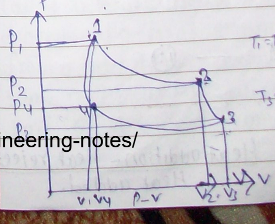
During process 2-3, working substance undergoes an isentropic expansion during which its pressure further decreases and its vol. further increases. During the process, no heat is supplied to the system and hence it produces work due to expense of its internal energy. Therefore, during the isentropic expansion process, entropy of the system remains const. and its temperature decreases as shown in curve line 2-3 in the graph.

* process 3-4 (Isothermal Heat Rejection):-

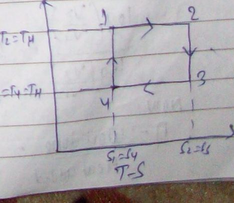
During process 3-4, heat is transferred from the working substance inside the cylinder to a high tempr sink having a temperature of T_L and the working substance undergoes an isothermal compression. During the isothermal compression, pressure of the substance increases, its volume decreases, its tempr remains const and the entropy decreases as shown in line 3-4 of the curve.

* process 4-1 (Isentropic Compression):-

During the process 4-1, working substance is further compressed under isentropic condn. such that its initial state is restored during which its pressure further increases and its vol. further decreases as shown in graph. During this isentropic compression, work supplied to the system increases its internal energy because there is no heat loss from the system. Therefore, during the isentropic compression process, entropy of system remains constant and its tempr increases as in the graph.



P-V



T-S

* Carnot Efficiency :-

process 2-3. (isentropic expn)

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

i.e $T_2V_2^{\gamma-1} = T_3V_3^{\gamma-1}$

or, $\left(\frac{V_2}{V_3}\right)^{\gamma-1} = \frac{T_3}{T_2} = \frac{T_2}{T_1}$ — ① $[\because T_1 = T_2,\ T_2 = T_4]$

Similarly for process 4-1

$\left(\frac{V_1}{V_4}\right)^{\gamma-1} = \frac{T_4}{T_1} = \frac{T_2}{T_1}$ — ⑪

from ① & ⑪

$\frac{V_1}{V_4} = \frac{V_2}{V_3}$ i.e $\frac{V_4}{V_3} = \frac{V_1}{V_2}$

Taking log on both sides.

$\log\left(\frac{V_3}{V_4}\right) = \log\left(\frac{V_2}{V_1}\right)$

$\frac{\log\left(\frac{V_3}{V_4}\right)}{\log\left(\frac{V_2}{V_1}\right)} = 1$ — (iii)

Now,

$\eta = \frac{\text{workdone}}{\text{Heat added}} = \frac{\text{Heat addition} - \text{Heat rejection}}{\text{Heat added}}$

$= 1 - \frac{HR}{HA}$

$= 1 - \frac{P_2V_2 \ln(V_3/V_4)}{P_1V_1 \ln(V_2/V_1)}$

$= 1 - \frac{P_2V_2}{P_1V_1}$

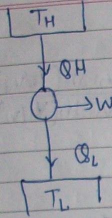
$= 1 - \frac{mRT_2}{mRT_1}$

$$\boxed{\eta = \left(1 - \frac{T_2}{T_1}\right)}$$

* Heat Engine, Heat pump & Refrigerator:-

Heat Engine :→

The device which operates on a cyclic process and converts heat energy into mechanical work is called a heat engine. The fig. below shows schematic diagram of a heat engine which takes (Q_1) heat from a high tempr Reservoir at T_H (source), converts some part of it into work (w) and rejects remaining part Q_L to a low tempr reservoir at T_L (sink)



→ The performance of a heat engine is measured by its efficiency, which is ratio of work output and heat supplied i.e

$$\eta = \frac{W}{Q_H} \text{ — ①}$$

Applying 1st law for a cyclic process

$$\oint dQ = \oint dW$$

$$\therefore Q_H - Q_L = W$$

So, eqn ① becomes

$$\eta = \frac{Q_H - Q_l}{Q_H} = \left(1 - \frac{Q_L}{Q_H}\right) \text{ — (II)}$$

now,

Applying 2nd law for cyclic process (for CM)

$$\oint dS_{cm} \geq \oint \Sigma \left(\frac{dQ_i}{T_i}\right)_{CM}$$

but change in entropy for a complete cycle is zero.

i.e $dS_{CM} = 0$ so,

$$0 \geq \frac{Q_H}{T_H} - \frac{Q_L}{T_L}$$

or $$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

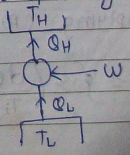
So eqn (II) becomes

$$\eta_{carnot} = \boxed{\eta_{rev} = 1 - \frac{T_L}{T_H}}$$

imp B.E

⑧ Define Heat pump & its Cop. Explain how performance of reversible and irreversible heat pump can be evaluated by applying first & 2nd law of thermodynamics

⇒ Heat pump is a device, operating on a cycle process, which takes heat from a low tempr reservoir at T_L and delivers it to a high tempr T_H with the help of external work. It maintains the tempr of desired space higher than the surrounding i.e



Now,
performance of a heat pump is measured by its coeff. of performance which is defined as the ratio of desired effect and the work supplied.

i.e $Cop = \frac{\text{Desired effect}}{\text{work input}}$ — (I)

In case of heat pump, desired effect is the amt. of heat supplied to the desired space (Q_H)

i.e $$(Cop)_{HP}^{\rightarrow \text{Heatpump}} = \frac{Q_H}{W} \quad \text{— (II)}$$

Now, Applying 1st law for cyclic process

$$\oint dQ = \oint dW$$

or $Q_L - Q_H = -W$ (∵ work is done on device)

$\therefore W = Q_H - Q_L$

∴ eqn (II) becomes

$$(COP)_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}} \quad \text{— (III)}$$

Now, Again, Applying CM 2nd law for cyclic process

$$\oint dS_{CM} (=0) \geq \oint \Sigma \left(\frac{dQ_i}{T_i}\right)_{sys}$$

or, $0 \geq -\frac{Q_H}{T_H} + \frac{Q_L}{T_L}$

For a reversible heat pump

ie $0 = -\frac{Q_H}{T_H} + \frac{Q_L}{T_L}$

or $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$

So eqn (III) reduces to

$$\boxed{(Cop)_{rev,HP} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{T_H}{T_H - T_L}} \quad \text{— (IV)}$$

but, for an irreversible heat pump, for same heating effect, we should increase the work input to overcome the frictional loses and so, Cop decreases

i.e $$\boxed{(Cop)_{irrev,HP} < \frac{T_H}{T_H - T_L}} \quad \text{— (V)}$$

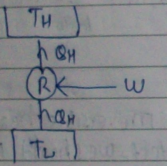
So, in general

$$\boxed{(Cop)_{HP} \leq \frac{T_H}{T_H - T_L}}$$

* Refrigerator :-

⇒ Refrigerator is a device, operating on a cyclic process, which takes heat from a low tempr reservoir at T_L (desired space) and delivers it to a high tempr (T_H). (sorrounding) with the help of external work. It maintains the tempr of a desired space lower than sorrounding

i.e



→ It's performance is also measured by COP and in case of refrigerator desired effect is the amt. of heat taken out from desired space (Q_L) i.e

$$(COP)_R = \frac{Q_L}{W} \quad — ①$$

Now,

Applying 1st Law in cyclic process.

$$\oint dQ = \oint dW$$

or $Q_L - Q_H = -W$

or $W = Q_H - Q_L$

So, ean ① becomes

$$(COP)_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1} \quad — ②$$

Then,

Acc to 2nd law,

$$(ds)_{c.m} (=0) \geq \Sigma \left(\frac{dQ_i}{T} \right)_{cm}$$

i.e $0 \geq \frac{Q_L}{T_L} - \frac{Q_H}{T_H}$

For reversible complete cycle

$$0 = \frac{Q_L}{T_L} - \frac{Q_H}{T_H}$$

or $\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$

So ean ② becomes

$$\boxed{(COP)_{rev.R} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L}} \quad — ③$$

but COP of irreversible

$$\boxed{(COP)_{irrev, R} \leq \frac{T_L}{T_H - T_L}} \quad — ④$$

So, combing ③ & ④

$$\boxed{(COP)_R \leq \frac{T_L}{T_H - T_L}}$$

* **Clausius inequality :-**

For any cyclic process, from 2nd law

$$\oint dS_{cm} (=0) \geq \oint \left(\frac{dQ_i}{T_i}\right)_{CM}$$

i.e

$$\oint \left(\frac{dQ}{T}\right) \leq 0 \quad — ①$$

with reference to eqn ①, we can conclude that for both power producing and consuming device or cycles, $\oint \left(\frac{dQ}{T}\right)$ is zero if cycle is reversible, -ve if irreverversible.

This statement is also known as Clausius inequality. Hence, for a cyclic, if

$\oint \frac{dQ}{T} < 0, \rightarrow$ irreversible

$\oint \frac{dQ}{T} = 0 \rightarrow$ reversible

$\oint \frac{dQ}{T} > 0 \rightarrow$ impossible.

[6 marks]

B.E W1 (Q) Write down the classical statements of 2nd law. Derive the equivalence between Kelvin planck's and Clausius statements of 2nd law of thermodynamics

⇒ The direction or possibility of a process which is the main feature of 2nd law of thermodynamics can be defined without using property 'Entropy'. These statements are called classical statements of 2nd law as follows:-

↳ **1st statement: (Kelvin-plank stat):-**

It states that, "it is impossible to construct a heat engine to work in a cyclic process whose sole effect is to convert all the heat supplied to it into an eqv. amt of work."

↳ **2nd statement:- (Clausius stat):-**

It states that, "It is impossible to construct a device to work in a cyclic process whose sole effect is the transfer of heat from a lower tempr to a body at higher tempr."

i.e

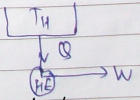


fig: impossible device defined by kelvin plank stat.

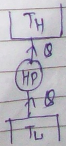
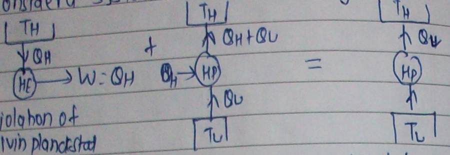


fig: impossible device defined by Clausius statement.

⇒ To prove the equivalence of these statements consider a system as shown in fig below.



violation of kelvin planck stat

Confirms to clausius stat

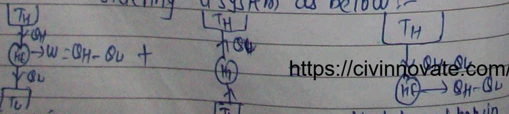
violation of clausius statements

i.e

It is obvious that, the pump obeys clausius statement and engine violates planck statement. If we consider this system as a whole, we find that QL units of heat are continously transferred from the heat sink at TL to heat are source at TH without any external input to the system, which is against the clausius statement. Thus, a violation of kelvin plank statement leads to violation of clausius statement.

Similary,

Considering a system as below:-



Confirms to kelvin plank

Violation of clausius

Violation of kelvin plank

i.e The heat pump violates the clausius statement while engine satisfies the kelvin-plank statement. But taken together, the net effect is that an amt. of heat (QH-QL) is taken from source at TH and is being completely converted into work without the exchange of heat with sink and this is against kelvin-plank statement. Thus, a violation of clausius statement leads to the violation of kelvin-plank statement.

Hence, for any process if kelvin-plank statement is satisfied then clausius statement will also be satisfied.

Chapter-6

Thermodynamic cycles

* Classification of practical cycles:-

According to power (work):-

1) power cycle:→

A cycle is said to be a power cycles, If it produces power or delivers work to the Sorrounding, when the cycle is executed net work is always +ve. eg: Brayton, otto, Diesel, Rankine cycle etc.

2) Refrigeration cycle:-

A cycle is said to be a refrigeration cycle, If power should be supplied to execute the cycle. It operates heat pump & Refrigeration. eg:- Vapor Compression refrigeration cycle.

According to working substance:-

① Gas cycle:-

A cycle is said to be a gas cycle. If the working substance remains in gaseous state throughout the cycle eg: Brayton, otto, diesel, etc

② vapor cycle:-

A cycle is said to be vapor cycle, If the working substance can undergo phase change throughout the cycle. eg: Rankine cycle

According to Combustion location:-

1) internal Combustion Cycle:-

If the Combustion takes place inside the power producing unit. eg: Otto, Disel.

2) External Combustion Cycle:-

If the Combustion takes place out-side the power producing unit.
eg: Brayton, Rankine

Imp Brayton cycle:→ (gas turbin / gas power engine

It is an ideal model for the power cycle consisting of a gas turbine. It consists of two isentropic and two isobaric processes i.e

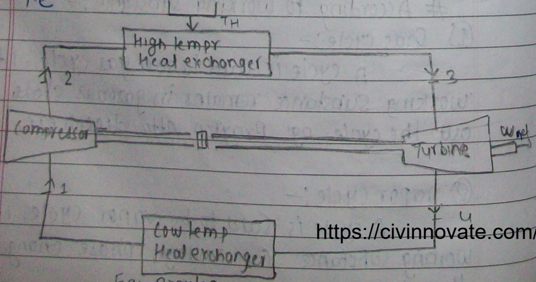


Fig: Brayton cycle.

process (1-2) Isentropic Compression:→

Low pressure and low tempr air from the low tempr heat exchanger is supplied to the compressor where it is compressed and delivered to high tempr heat exchanger. process occuring in the compressor is assumed to be isentropic process. Hence, during this process, pressure increases, sp. vol decreases and entropy remains const and its tempr increases as shown in the curve.

process (2-3) (Isobaric Heat addition):-

Heat is supplied to the high tempr heat exchanger from an external source and the working substance is heated under const pressure. Hence, during the process, sp. vol, tempr and entropy of air increases as in curve.

process 3-4 (Isentropic Expansion):-

High tempr and pressure air leaving the high tempr heat exchanger is supplied to the turbine. The turbine produce work by consuming energy carried by air at the turbine inlet. The process in turbine is assumed to be isentropic expansion. So, pressure decreases, sp. vol. increases, entropy remains const, tempr decreases as in the curves.

process 4-1 (isobaric heat rejection):—

The Exit air from the turbine is delivered to low tempr heat exchanger where it rejects heat to low tempr sink such that its initial state is restored. Heat rejection occurs at const. pressure. Thus, sp. vol, tempr & entropy of air decreases as in curve.

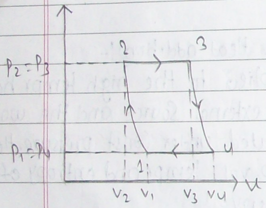


Fig: P-V diagram

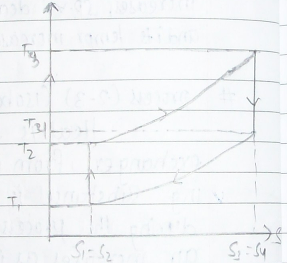


Fig: T-S diagram

* Efficiency:→

The efficiency of Brayton cycle is,

$$\eta = \frac{\text{work done}}{\text{Heat addition}} = \frac{\text{Heat added} - \text{Heat rejected}}{\text{Heat added.}}$$

$$= 1 - \frac{\text{Heat rejection}}{\text{Heat addition}}$$

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

$T_3 - T_2 - T_4$

$$\boxed{\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}} \quad \text{——} \quad ①$$

also, for isentropic process (cyclic + adiabatic) betn 1 to 2 & 3 to 4, we have,

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

$$\text{so,} \quad \frac{T_2^{\gamma}}{P_2^{\gamma-1}} = \frac{T_1^{\gamma}}{P_1^{\gamma-1}}$$

$$\text{or,} \quad \left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{——} \quad Ⓐ$$

Similarly,

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

but $P_2 = P_3$, $P_1 = P_4$ so

eqn Ⓐ & Ⓑ became identical i.e.

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

$$\text{or,} \quad \frac{T_4}{T_3} = \frac{T_1}{T_2}$$

using componendo and dividendo

$$\frac{T_4}{T_3} = \frac{T_4 - T_1}{T_3 - T_2} \quad \text{——} \quad Ⓒ$$

from ① & Ⓒ

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

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

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

$$\boxed{\eta = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}}$$

Lt

which is the efficiency in terms of pressure ratio;

$r_p = P_2/P_1$

also, $Tv^{\gamma-1} = \text{Const}$

So, $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ — (ii) So,

$$\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$\boxed{\eta = 1 - \left(\frac{1}{\rho}\right)^{\gamma-1}}$$

$\rho = \frac{V_1}{V_2}$ = Compression ratio.

Lt

→ The efficiency of Brayton cycle increases with the ↑ in pressure ratio.

Rankine Cycle:-

Rankine cycle is an ideal model for the power cycle consisting of a steam turbine. The major components (devices) of the Rankine cycle are shown is fig;

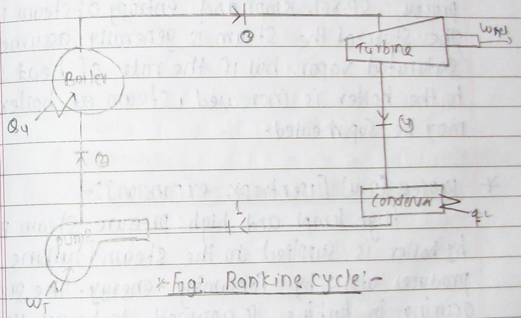


*Fig: Rankine cycle:-

* process (1-2) (Isentropic pumping process):-

Low pressure saturated liq. from the low pressure condenser is supplied to the high pressure boiler with the help of a pump. The pumping process is assumed to be isentropic. During the process, working substance remains in liquid state, its sp. volume remains almost const, pressure increases and entropy remains const.

* process 2-3 (Isobaric heat addition):-

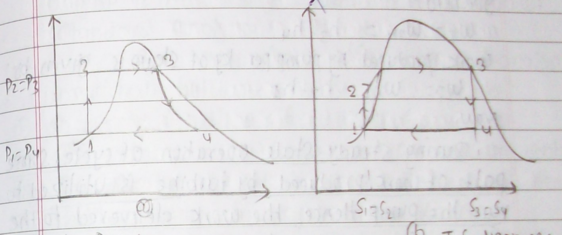
Heat is supplied to the boiler from an external source and the boiler produces steam by heating the liquid water. The heat addition in boiler occurs at const. pressure. Hence, during this process, Sp.vol, tempr and entropy of steam increases. The state of the steam is generally assumed as saturated vapor. but if the rate of heat supply to the boiler is increased, steam at boiler outlet may be superheated.

* process (3-4) [isentropic expansion]:-

High tempr and high pressure steam produced by boiler is supplied to the steam turbine which produces work by consuming energy. The process ocuring in turbine is assumed to be an isentropic expansion. Hence, during process, pressure decreases, Sp.vol. further increases but entropy remains const & its tempr decreases.

* process (4-1) (isobaric Heat rejection):→

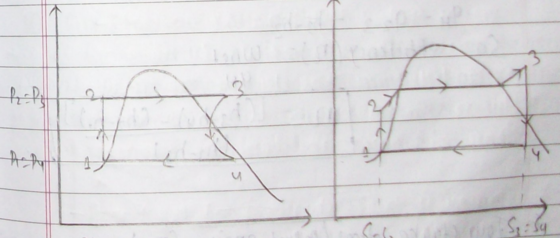
The steam from the turbine exist is delivered to the condenser where it rejects heat to its sorroundings (cooling water) and gets condensed back into salt liqud. It occurs at const. pressure during which Sp.vol, entropy decreases where its tempr remains const.



ⓐ P-V diagram

ⓑ T-S diagrome

(with saturated vapor at Boiler outlet)



ⓐ P-V

(with superheated vapor at Boiler outlet)

* Efficiency of Rankine Cycle:→

work produced by turbine per kg of steam is given by:

$W_T = W_{34} = h_3 - h_4$

work produced by pump per kg of steam is given by:

$W_P = W_{12} = h_2 - h_1$

Now,

During steady state operation of cycle, some part of work produced by turbine is utilized to run the pump Hence, the work delivered to the surroundings as given by:

$W_{net} = W_T - W_P = [(h_3 - h_4) - (h_2 - h_1)]$

Now,

heat supplied to steam in boiler is

$q_H = q_{2-3} = h_3 - h_2$

So. efficiency $(\eta) = \frac{W_{net}}{q_H}$

$$\boxed{\eta = \frac{[(h_3 - h_4) - (h_2 - h_1)]}{(h_3 - h_2)}}$$

* Four stroke disel/petrol engine (I.C)

→ Suction stoke

→ compression stoke

→ power (expn) stoke

→ Exhaust stroke

Imp

Air Standard Analysis:-

The idealized analysis of the cycle considering only air is the working substance is called an air standard analysis.

The assumptions of air standard analysis are listed below:-

(i) The cycle consists of fixed mass of air.

(ii) The expansion and compression processes are isentropic.

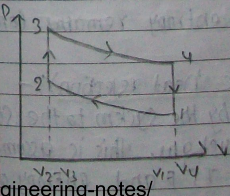
(iii) The combustion process is replaced by an eqv. heat addition process from an external source

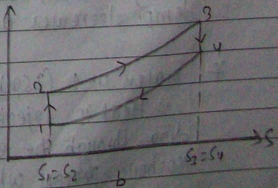
(iv) The exhaust process is replaced by an eqv. heat rejected process to an external sink.

(v) The properties of air (Cp, Cv, R) remains const.

① Air standard otto cycle:-

It is an idealized model for the operation of petrol engines. It consists of two isentropic and two isochoric processes as shown in fig.





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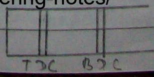


* process 1-2 (isentropic compression):→

At the begining, piston will be at Bottom dead centre (BDC) and the cylinder contains mixture of air and petrol. When the piston travels from BDC to TDC, the mixture inside it gets compressed insentropically during which vol decreases, pressure increases, tempr increases, and entropy remains const.

* process 2-3 (Isochoric Heat addition):→

At the end of compression stroke, spark plug provides an electric spark and petrol burns. Then heat is added as an isochoric process during which P, T and entropy increases but vol. remains const.

* process 3-4 (isentropic expansion):-

Due to the impact of burning, piston gets expanded form TDC to BDC at isentropic condn during which pressure decreases, vol. increases, tempr decreases and entropy remains const.

* process 4-1 (Isochoric heat rejection):-

Heat is rejected by the system to the sorrounding through the exhaust gas. This is assumed to be isochoric process where T, p and entropy of the system decreases.

* Efficiency of an air standard otto cycle

⇒ Efficiency $(\eta) = 1 - \frac{q_L}{q_H}$

where q_L = heat rejected per kg of air per cycle

q_H = heat added per kg of air per cycle

and, $q_L = q_{4-1} = C_v(T_4 - T_1)$ — (i)

so, $q_H = P_{2-3} = C_v(T_3 - T_2)$ — (ii)

Or, $(\eta) = 1 - \frac{T_4 - T_1}{T_3 - T_2}$

Now, applying T-V relation for isentropic compress process 1-2 and isentropic expansion process 3-4

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

$$\left(\frac{T_3}{T_4}\right) = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$\because (V_3 = V_2, V_4 = V_1)$

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

Or, $\frac{T_4}{T_3} = \frac{T_1}{T_2} = \frac{T_4 - T_1}{T_3 - T_2}$ [using componendo & dividendo]

So eqn (ii) becoms

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

Now also

$$\boxed{\eta = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma-1} = 1 - \left(\frac{1}{r}\right)^{\gamma-1}} \text{ — (iv)}$$

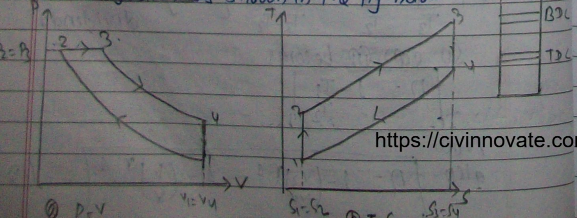
where $r = \frac{V_1}{V_2}$ is Called Compression ratio

Thus,
eqn: (v) is the η efficiency is the terms of compression ratio.

It shows η increases with increase in Compression ratio. Although high compression ratio is desirable for high efficiency but in reality high pressure ratio causes high tempr and there is a limitation to which a real engine cylinder can withstand maximum tempr or pressure. In real petrol engine cycle, 'r' is generally in betn 8 to 12.

Air standard diesel cycle :→

It is an idealized model for the operation of diesel engine. It consists of isentropic, compression isobaric heat addition, isentropic expansion, & isochoric heat rejection as shown in the fig below



(a) P-V

(b) T-S

* Process 1-2 (Isentropic Compression):–

↳ At the beginning of the compression, piston will be at BDC and the cylinder contains air. when the piston travels from BDC to TDC, the air inside cylinder is compressed under isentropic condition during which, its vol. decreases, tempr increases and entropy remains const.

* Process 2-3 (Isobaric heat addition):→

↳ At the end of compression stroke, the tempr of air reaches greater than self ignition tempr of diesel. At this stage fuel injector nozzle supplies diesel into cylinder and diesel gets self burnt and piston move from TDC towards BDC with heat addition isobarically during which 'p' remains const, vol, tempr and entropy of system increases.

* Process 3-4 (Isentropic expansion):–

↳ Due to the impact of burning, piston gets further expansion under isentropic condition during the process, pressure decreases, tempr decrease, vol. increa entropy remain const.

* Process 4-1 (Isochoric Heat Rejection):–

↳ Heat is rejected by the system to the surrounding through the exhaust gas and this process is replaced by an eqv. const vol (isochoric) heat rejection during which T, P and entropy imp * **Efficiency of an Air Standard disel Cycle:-**

→ Efficiency of an ideal diesel cycle is given as

$$\eta = 1 - \frac{q_L}{q_H} \quad \text{— ①}$$

where,

$q_L = q_{4-1} = C_v(T_4 - T_1)$ (during const. vol)

and, heat added to the system during const. pressure process 4-1 is given as

$q_H = q_{2-3} = C_p(T_3 - T_2)$

So, eqn ① becomes

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

Now

$$\eta = 1 - \frac{1}{\gamma}\frac{T_1}{T_2}\left[\frac{T_4/T_1 - 1}{T_3/T_2 - 1}\right] \quad \text{— 2}$$

Now,

applying tempr - vol relationship for isentropic compression process 1-2;

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = (r)^{\gamma-1}$ — Ⓐ r = compression ratio.

Similarly, applying T-V relation for isobaric heat addition process 2-3,

$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \alpha$ — Ⓑ is called cut-off ratio

because heat addition gets cut off from state 3

again applying T-V relⁿ for isentropic expansion process 3-4;

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma-1}$$

but $V_4 = V_1$ so,

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_1}\right)^{\gamma-1}$$

$$\frac{T_4}{T_3} = \left(\frac{\alpha}{r}\right)^{\gamma-1} \quad \text{— ③}$$

Now,

multiplying eqn Ⓐ, Ⓑ & ③ we get

$$\frac{T_4}{T_3} \times \frac{T_3}{T_2} \times \frac{T_2}{T_1} = \left(\frac{\alpha}{r}\right)^{\gamma-1} \cdot \alpha \cdot (r)^{\gamma-1}$$

$$= (\alpha)^{\gamma} \quad \text{— ④}$$

Thus, eqn ② becomes

$$\boxed{\eta = 1 - \frac{1}{\gamma}\left(\frac{1}{r}\right)^{\gamma-1}\left[\frac{\alpha^{\gamma} - 1}{\alpha - 1}\right]} \longleftarrow$$

which is the real expression for the efficiency of diesel cycle.

8 mark B.E. Past question

1) Define isentropic process. Derive relations for an ideal gas and an incompressible substance

② explain entropy. Derive the relations for entropy for an ideal gas & an incompressible substance.

③ Explain the directional feature of the natural process with one example. State the second law of thermodynamic for an isolated system. explain the entropy generation.

④ Dervice the expn of entropy generation for a control mass → RHTRs RWTRs.

⑤ State the entropy change statement for a control vol & derive an expn for its entropy generation.

⑥ write down the classical statements of second law. Derive the equivalence between kelvin plank's & Clausius's statement of 2nd law of thermodynamics

⑦ Deff. betn heat engine & refrigerator. Also explain the factors used for their performance evaluation

⑧ Derive the relations for entropy for ideal gases. Also show the equivalence of Clausius and kelvin's eqv.

⑨ Define heat pump & its Cop. Explain how 2nd law can be applied to analyse the performance of the heat pump.

⑩ Define reversible heat transfer reservoir and reversible work transfer reservior. Derive expression for change in entropy for reversible heat transfer reservior & reversible work transfer reservoir.

⑪ Define heat pump & Cop. Explain how performance of reversible & irreversible heat pump can be evaluated by applying first & 2nd law of thermodynamics.

⑫ Derive expn for change in entropy for an ideal gas incompressible substance.

Chapter 7

Introduction to heat transfer

Modes of Heat Transfer :-

1 Conduction:-

It is due to property of matter which allows the passage for heat energy even its parts are not in motion relative to one another.

Magnitude of conduction of heat transfer is given by Fourier equation;

$$\boxed{Q = -KA\frac{dT}{dx}} \text{ --- (i)}$$

Q = heat transfer rate (watt)

K = Thermal conductivity of material (w/m.k)

A = Cross sectional area of material normal to the direction of heat flow(m2) and

$\frac{dT}{dx}$ → Tempr gradient within the material (k/m)

→ The -ve sign in eqn(i) indicates that heat flows in the direction of decreasing temperature.

2) Convection:→

It occurs in fluid medium & heat is transferred by the actual movement of the molecules. Magnitude of convection heat transfer is given by newton's law of cooling

$$\boxed{Q = hA(T_s - T_\infty)} \text{ --- ii}$$

where,

$Q \rightarrow$ heat transfer rate (w)

$h \rightarrow$ convection heat transfer coeff (w/m2.k)

$A \rightarrow$ Surface area of Solid containing the liquid (m²)

$T_s \rightarrow$ Solid surface tempr

$T_\infty \rightarrow$ free stream tempr of fluid.

'h' depends upon density, viscosity, sp. heat (c), thermal conductivity.

③ Radiation:→

It can occur without any medium and is transferred in the form of EMW. magnitude of radiation heat exchange between two practical bodies at tempr T_1 and T_2 is given by Stefan-Boltzmann law,

$$Q = \epsilon\sigma A(T_1^4 - T_2^4) \quad \text{— (iii)}$$

where

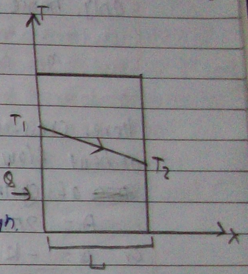
$Q \rightarrow$ heat transfer rate (w)

$\epsilon \rightarrow$ emissivity

$A \rightarrow$ Surface area (m2)

$\sigma \rightarrow$ Stefan-Boltzmann const $= (5.67 \times 10^{-8}\ w/m^2)$

One dimensional Steady State Heat Conduction through a plane wall:→



Consider. - .

Then

$$Q = -KA\frac{dT}{dx}$$

or, $Q.dx = -KAdT$

Now,

integrating with associated boundary condn.

$$Q.\int_0^L dx = -\int_{T_1}^{T_2} KAdT$$

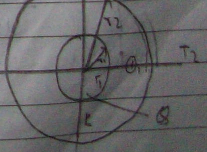
or, $Q.L = -KA(T_2 - T_1)$

or, $Q = \dfrac{-KA(T_2 - T_1)}{L}$

or, $\boxed{Q = \dfrac{KA}{L}(T_1 - T_2)}$ Ans.

Radial Steady State Heat Conduction through a Hollow Cylinder:→

Consider! - - - - .



∵ the tempr gradient exists in radial direction only, hence we can apply fourier eqn as;

$$Q = -kA\frac{dT}{dr} \quad — ①$$

Here, cross-sectional area normal to the direction of heat flow is given by curved surface area ~~area~~ of cylinder, so,

$$A = 2\pi rL$$

$$\text{or } Q = -k(2\pi rL)\frac{dT}{dr}$$

$$\text{or } Q.\frac{dr}{r} = -k(2\pi L)dT$$

on integrating with associated boundary conditions

$$Q\int_{r_1}^{r_2}\frac{dr}{r} = -\int_{T_1}^{T_2}k(2\pi L)dT$$

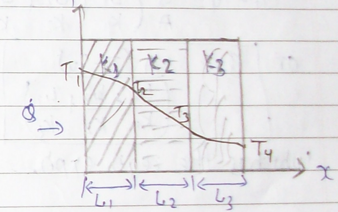
$$\text{or, } Q.\ln\left(\frac{r_2}{r_1}\right) = -2\pi kL(T_2-T_1)$$
$$= 2\pi kL(T_1-T_2)$$

$$\therefore \boxed{Q = \frac{2\pi kL(T_1-T_2)}{\ln\left(\frac{r_2}{r_1}\right)}}$$

Heat Conduction through Composite Structures:→

ⓐ Through Composite plane wall:→

Consider a composite plane wall consisting of three layers of three diff. materials. Thickness of each layer are L_1, L_2 & L_3 resp. and thermal conductivities of each layers are K_1, K_2 and K_3 resp. Two opposite faces of the composite wall subjected to tempr of T_1 & T_4 and interfaces tempr are T_2 and T_3 resp.



Now,

For steady state heat transfer, heat flowing through each layer should be same i.e

$$\dot{Q} = \frac{K_1A(T_1-T_2)}{L_1} \quad — ①$$

$$\dot{Q} = \frac{K_2A(T_2-T_3)}{L_2}$$

$$\dot{Q} = \frac{K_3A(T_3-T_4)}{L_3}$$

Now,
rearranging above eqns we get

$$T_1 - T_2 = \frac{\dot{Q} L_1}{A k_1}$$

$$T_2 - T_3 = \frac{Q L_2}{A k_2}$$

$$T_3 - T_4 = \frac{Q L_3}{A k_3}$$

Now,

Adding them we get

$$T_1 - T_4 = \frac{Q}{A}\left(\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3}\right)$$

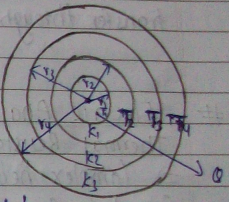
or

$$\boxed{Q = \frac{A(T_1 - T_4)}{\left(\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3}\right)}}$$

which is the reqn exph.

ⓑ Through Composite Hollow cylinder:→

Consider a composite hollow cylinder consisting of three cylindrical layers of three diff. materials as in fig. The first layer with inner and outer radii r_1 & r_2 has a conductivity k_1, ~~Second~~ Second layer with inner & outer radii of r_2 & r_3 has a thermal conductivity of k_2 and third layer with inner & outer radii of r_3 & r_4 has a thermal conductivity of k_3. Inner & outer surfaces of composite layers are subject to tempr T_1 & T_4 and interface tempr and T_2 & T_3 resp.



Now,

For steady state heat transfer, heat flowing through each layers should be same i.e

$$Q = \frac{2\pi k_1 L (T_1 - T_2)}{\ln(r_2/r_1)} \text{ i.e } (T_1 - T_2) = \frac{Q}{2\pi L}\frac{\ln(r_2/r_1)}{k_1}$$

$$\dot{Q} = \frac{2\pi k_2 L (T_2 - T_3)}{\ln\left(\frac{r_3}{r_1}\right)} \text{ i.e } (T_2 - T_3) = \frac{Q}{2\pi L}\frac{\ln(r_3/r_2)}{k_2}$$

$$\dot{Q} = \frac{2\pi k_3 L (T_3 - T_4)}{\ln(r_4/r_3)} \text{ i.e } (T_3 - T_4) = \frac{Q}{2\pi L}\frac{\ln(r_4/r_3)}{k_3}$$

Now,

adding above eqn we get

$$T_1 - T_4 = \frac{Q}{2\pi L}\left(\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right]$$

or, $$\boxed{\dot{Q} = \frac{2\pi L (T_1 - T_4)}{\left[\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right]}}$$

which is the reqd expression for radial heat transfer through a composate hollow cylinder.

Electric Analogy for Heat transfer and Thermal Resistance:→

⇒ Complex heat transfer problems can also be solved by converting the given problem into an eqv. electric circuit and applying appropriate net work theorem.

To compare the analogous parameter, we can start with ohm's law is

$I = \frac{\Delta V}{R}$ – (i) which shows that current (I) flows due to different in electric potential (ΔV) and the property by virtue of which it opposes the flow of current through it (electric resistance)

Thus,

In the similar manner,

we can express heat ($\dot{Q}$) flows due to the diff. in tempr (ΔT) and property of substance by virtue of which it opposes the flow of heat (thermal resistance)

i.e $\dot{Q} = \frac{\Delta T}{R_{th}}$ — (ii)

$\downarrow$ K/W or °C/W

Now,

(i) Thermal resistance of a plane wall:→

we know,

$Q = \frac{T_1 - T_2}{L/AK}$ (Through plane)

Comparing it with $Q = \frac{\Delta T}{R_{th}}$

$$\boxed{R_{th} = \frac{L}{AK}}$$

(ii) Thermal resistance of a Hollow cylinder:–

$$Q = \frac{2\pi KL (T_1 - T_2)}{\ln(r_2/r_1)} = \frac{T_1 - T_2}{\frac{\ln(r_2/r_1)}{2\pi KL}}$$

Comparing with $Q = \frac{\Delta T}{R_{th}}$

$$\boxed{R_{th} = \frac{\ln(r_2/r_1)}{2\pi KL}}$$

(iii) Thermal resistance of convective medium:–

$Q = hA(T_s - T_\infty) = \frac{(T_s - T_\infty)}{(1/hA)}$

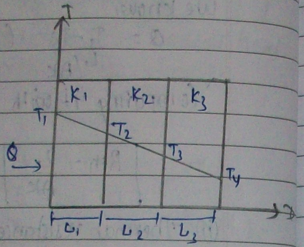
Comparing with $Q = \Delta T / R_{th}$

$$\boxed{R_{th} = 1/hA}$$ Ans

B.E imp

Heat transfer through a composite plane wall using Electric Analogy Approach:-

⇒ Consideration same as before



Now,
The equivalent electric circuit for a composite plane wall shown above is given as:-

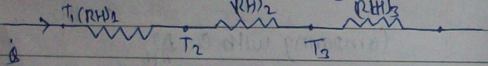


Fig: eqv. electric circuit for a composite plane wall

Now.

Fig: eqv. electric circuit for a composite plane wall

Now,
In this case, the same amt. of heat flows through each layer, hence all thermal resistances are arranged in series. Whenever heat flows through a thermal resistance, there will be a tempr drop (analogous to voltage drop in case electric circuit). Thermal resistances for each layer of the plane wall are given as:

$$(Rth)_1 = \frac{L_1}{AK_1}, \quad (Rth)_2 = \frac{L_2}{AK_2}, \quad (Rth)_3 = \frac{L_3}{AK_3}$$

So,

$$\therefore Req = (Rth)_1 + (Rth)_2 + (Rth)_3$$

$$= \frac{1}{A}\left(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right)$$

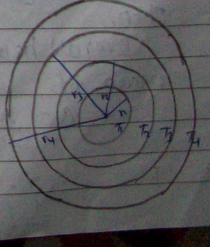
Then, overall heat transfer for a composite plane wall is given by,

$$\dot{Q} = \frac{\Delta T}{Req.} = \frac{T_1 - T_4}{\frac{1}{A}\left(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right)}$$

$$\boxed{\dot{Q} = \frac{A(T_1 - T_4)}{\left(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right)}}$$ is the reqd eqn.

Heat transfer through a composite cylinder using Electric Analogy Approach:-

Consideration similar as before.



The, equivalent electric circuit for a composite cylinder shown above is as:

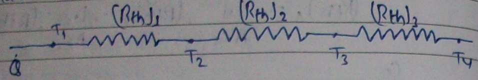


fig: Eqv. electric circuit for a composite cylinder

Hence,

In this case also the same amt. of heat flows through each layer, hence all thermal resistances are arranged in series. Then, the thermal resistances for each layer of composite cylinder are given as:-

$(R_{th})_1 = \frac{\ln(r_2/r_1)}{2\pi k_1 L}$, $(R_{th})_2 = \frac{\ln(r_3/r_2)}{2\pi k_2 L}$ & $(R_{th})_3 = \frac{\ln(}{2\pi k_3 L}$

Then,

Eqv. thermal resistance is given as:-

$$R_{eq} = (R_{th})_1 + (R_{th})_2 + (R_{th})_3$$

$$= \frac{1}{2\pi L}\left[\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right]$$

Then,

Overall heat transfer for a composite cylinder is given by

$$Q = \frac{\Delta T}{R_{eq}}$$

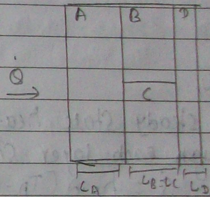
i.e $$= \frac{T_1 - T_4}{\frac{1}{2\pi L}\left(\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right)}$$

$$\dot{Q} = \frac{2\pi L(T_1 - T_4)}{\left[\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right]}$$

which is the reqd expression.

Appⁿ of Electric Analogy Approach:-

Electric analogy becomes more appropriate when the composition of the wall becomes more complex. For eg for a complex plane wall as in figure



Then

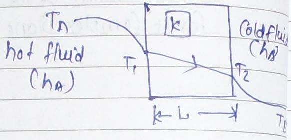
Eqv. thermal resistance for given circuit is given by

$$\boxed{R_{eq} = (R_{th})_A + \frac{(R_{th})_B \times (R_{th})_C}{(R_{th})_B + (R_{th})_C} + (R_{th})_D}$$

Combined Heat transfer and overall Heat Transfer Coeff.

1) Plane wall subjected to convective medium on both sides:-

Consider a plane wall having a thickness of L and a thermal conductivity of k as in fig. one of its face is exposed to a hot fluid with Tempr T_A and connective heat transfer coff. h_A while opposite face is exposed to a cold fluid with tempr T_B and connective heat transfer coeff. h_B.



Now,

For steady state heat transfer, heat flow through each layer should be same i.e

$$\dot{Q} = h_A \cdot A (T_A - T_1)$$

$$\dot{Q} = \frac{KA}{L}(T_1 - T_2)$$

$$\dot{Q} = h_B A (T_2 - T_B)$$

Now,

rearranging them, we get

$$T_A - T_1 = \frac{\dot{Q}}{A} \cdot \frac{1}{h_A}$$

$$T_1 - T_2 = \frac{\dot{Q}}{A} \cdot \frac{L}{K}$$

$$T_2 - T_B = \frac{\dot{Q}}{A} \cdot \frac{1}{h_B}$$

Now, adding them we get

$$T_A - T_B = \frac{\dot{Q}}{A}\left(\frac{1}{h_A} + \frac{1}{k} + \frac{1}{h_B}\right)$$

or,

$$\boxed{\dot{Q} = \frac{A(T_A - T_B)}{\left(\frac{1}{h_A} + \frac{L}{k} + \frac{1}{h_B}\right)}}$$

Now,

It can be expressed as $\dot{Q} = UA(T_A - T_B)$

So,

$$U = \frac{1}{\frac{1}{h_A} + \frac{L}{K} + \frac{1}{h_B}}$$

is called overall heat transfer coefficient.

IMP BE ②

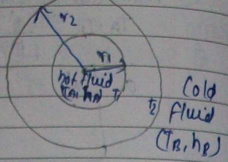
Hollow cylinder subjected to convective medium on both sides:-

Consider a hollow cylinder with inner and outer radii of r_1 and r_2, length L and thermal conductivity K as in fig. The inner surface of the cylinder is exposed to a hot fluid with tempr T_A and connective heat transfer coeff h_A, whereas outer surface of cylinder is exposed to a cold fluid with tempr T_B and connective heat transfer coeff of h_B

i.e

Now,

For steady state heat transfer, heat flow through each layer should be same i.e.



$$\dot{Q} = h_A A_1 (T_A - T_1)$$

$$\dot{Q} = \frac{2\pi k L}{\ln(r_2/r_1)} (T_1 - T_2)$$

$\dot{Q} = h_B A_2 (T_2 - T_B)$, A_1 & A_2 are inside & outside Curved surface area.

Now, rearranging them.

$$T_A - T_1 = \frac{\dot{Q}}{A_1} \cdot \frac{1}{h_A}$$

$$T_1 - T_2 = \dot{Q} \cdot \frac{\ln(r_2/r_1)}{2\pi k L}$$

$$T_2 - T_B = \frac{\dot{Q}}{A_2} \cdot \frac{1}{h_B}$$

Now, adding them.

$$T_A - T_B = \dot{Q}\left(\frac{1}{h_A A_1} + \frac{\ln(r_2/r_1)}{2\pi k L} + \frac{1}{h_B A_2}\right) \text{ — Ⓐ}$$

or,

$$\dot{Q} = \frac{A_1 (T_A - T_B)}{\left(\frac{1}{h_A} + \frac{A_1}{2\pi k L} \ln\left(\frac{r_2}{r_1}\right) + \frac{A_1}{A_2} \frac{1}{h_B}\right)} \text{ — (I)}$$

also,

$$\dot{Q} = \frac{A_2 (T_A - T_B)}{\left(\frac{A_2}{A_1 h_A} + \frac{A_2}{2\pi k L} \ln\left(\frac{r_2}{r_1}\right) + \frac{1}{h_B}\right)} \text{ — (II)}$$

Comparing (I) & (II) resp. with

$$\dot{Q} = U_1 A_1 (T_A - T_B)$$

$$\dot{Q} = U_2 A_2 (T_A - T_B)$$

we get,

$$\boxed{U_1 = \frac{1}{\left(\frac{1}{h_A} + \frac{A_1}{2\pi k L} \ln\left(\frac{r_2}{r_1}\right) + \frac{A_1}{A_2} \frac{1}{h_B}\right)}}$$

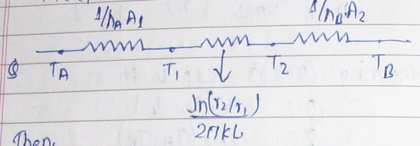
→ where $A_1 = 2\pi r_1 L$, $A_2 = 2\pi r_2 L$

$$\boxed{U_2 = \frac{1}{\left(\frac{A_2}{A_1} \cdot \frac{1}{h_A} + \frac{A_2}{2\pi k L} \ln\left(\frac{r_2}{r_1}\right) + \frac{1}{h_B}\right)}}$$

are called inside overall heat transfer coeff and outside overall heat transfer coeff.

* Alternative method (Electric Analogy approach):-

The eqv. Circuit for heat transfer is



Then,

$$R_{eqv} = \frac{1}{h_A A_1} + \frac{\ln(r_2/r_1)}{2\pi kL} + \frac{1}{h_B A_2}$$

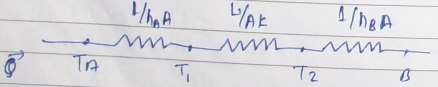
Then, $$\dot{Q} = \frac{\Delta T}{R_{eq}} = \frac{(T_A - T_B)}{\left(\frac{1}{h_A A_1} + \frac{\ln(r_2/r_1)}{2\pi kL} + \frac{1}{h_B A_2}\right)}$$

which is identical to eqn Ⓐ then follow similar as above to find U_1 & U_2

* Alternative to plane wall subjected to convective medium on both sides (Electric Analog approach):-

Same fig.

The eqv. electric network is,



Then,

$$R_{eq} = \frac{1}{A}\left(1/h_A + L/k + 1/h_B\right)$$

Then,

overall heat transfer for a composite plane wall is given by.

$$\dot{Q} = \frac{\Delta T}{R_{eq}} = \frac{T_A - T_B}{1/A\,(1/h_A + L/k + 1/h_B)}$$

$$\boxed{\dot{Q} = \frac{A(T_A - T_B)}{(1/h_A + L/k + 1/h_B)}} \text{ — ①}$$

which company with $\dot{Q} = UA(T_A - T_B)$

$$\boxed{U = \frac{1}{(1/h_A + L/k + 1/h_B)}}$$ is overall heat transfer coeff.

Nature of Heat radiation:→

Radiation is an electromagnetic phenomenon of varying wavelength closely allied to the transmission of light and radio. & requires no transfer medium.

imp * black body:- A body which absorbs all the lights fall on it completely (perfect radiator).

imp * If the body emits energy across the black body wavelength spectrum but only a fraction of the power of black body, then is called grey body.

Note:- The terms black and grey donot necessarily refer to the color of body, rather they merely describe its effectiveness as a radiator. A black-body is a perfect radiator; a grey body is not a perfect radiator

Radiation Surface-properties:-

Surfaces are capable of emitting, absorbing reflecting or transmitting radiant energy.

i.e $E_{incident} = E_{absorbed} + E_{reflected} + E_{transmitted}$

or, $\frac{E_{absorbed}}{E_{incident}} + \frac{E_{reflected}}{E_{incident}} + \frac{E_{transmitted}}{E_{incident}} = 1$

i.e $\boxed{\alpha + \rho + \tau = 1}$, where, α = absorptivity.

$\rho \rightarrow$ reflectivity

τ = transmissivity

For a black body:-

It absorbs all the energy incident upon it

So,

$\alpha = 1, \ \rho = \tau = 0$

For white body which reflects all the energy incident upon it, $\rho = 1$ hence $\alpha = \tau = 0$

For grey body emissivity (ε_s), which is ratio of grey surface emission to black surface emission

i.e $\varepsilon_s = \frac{E_s}{E_B} < 1$.

BE Question (6marks) Q.no.7

1) Derive expression for inside & outside overall heat transfer co-efficent for a hollow cylinder subjected to convection medium on both sides

② Define thermal resistance, Derive an expn for heat transfer through composite plane wall of three different layrs of diff materials using electric, analogues approach. [2times . 4times]

③ Derive an expn for stady state radial heat conduction through a hollow cylinder. also derive expn for its thermal resistance.

④ Define terms black body & gray body.

⑤ Derive an expn for heat transfer through a mild steel pipe with a layer of insulation in the outside. Take tempr of fluid in pipe as t_{fluid}, temp of air as t_{air} and length of pipe as L ($t_{fluid} > t_{air}$)

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