UNIT-1

Introduction:- Thermodynamics is the science of energy transfer and its effect on the physical properties of substances.

It is a classical (or) macroscopic science, which studies heat and work transfer with matter which bring about changes in the macroscopic properties of a substance that are measurable.

- Based ~~on~~ upon observations of common experience, changes in the properties of substance have been formulated into 4 Thermodynamic laws. These laws govern the principle of energy conversion.

The application of the thermodynamic laws and principles are found in all fields of energy technology.

Four Laws
① First law - concept of internal energy
② Zeroth Law: concept of Temperature
③ second law - Limit of converting heat into work, principle of increase entropy
④ Third law - Absolute zero of Entropy

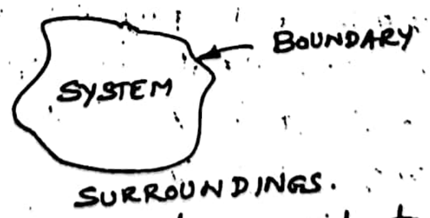
Examples:-
① Steam and Nuclear power plants
2) I.C engines
3) Gas turbines
4) Refrigeration & Air-conditioning
5) compressors etc.,

Terms (or) definitions:-

1) **Thermodynamic system:-** It is a prescribed region (or) space (or) finite quantity of matter on which we focus our attention to study its properties.

2) **surroundings:-** other than the system everything else is known as surroundings.

3) **Boundary:-** An imaginary closed curve which separates system from its surroundings is called Boundary. The boundary may be either fixed (or) moving.

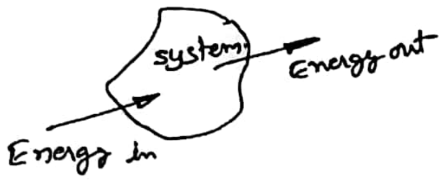


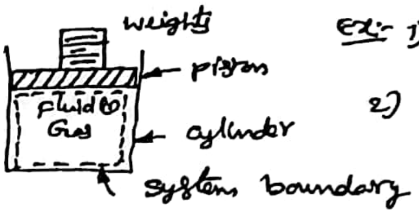
4) **Universe:-** system plus surroundings put together is known as universe. Hence it has no boundaries and is of infinite size.

Types of Thermodynamic Systems:- Based on the mass and energy transfer across the boundary, the systems are divided into three types.

1) closed system 2) open system 3) Isolated system.

① **closed system:-** In a closed system, the mass is fixed. There is no mass transfer across the boundaries but energy transfer may takes place into (or) out of the systems.





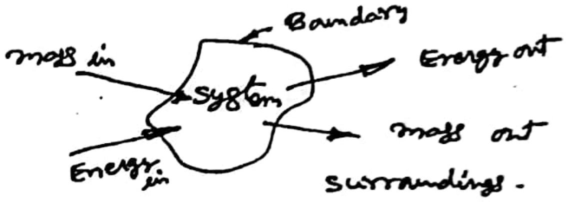
Ex:- 1) Hot coffee in a steel tumbler
2) Heating the Gas in a cylinder.

No mass transfer.

Certain quantity of fluid in a cylinder bounded by a piston constitues a closed system.

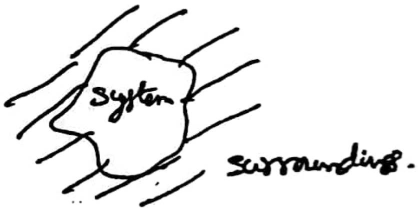
② Open system:- In an open system both mass and energy crosses the boundary.

Ex:- 1) compressor
2) Nozzle.



③ Isolated system:- In isolated system, there is neither energy transfer nor mass transfer occurs across the boundaries. i.e., Not having any interaction with surroundings.

Ex:- 1) Thermo flask
2) Insulated chamber



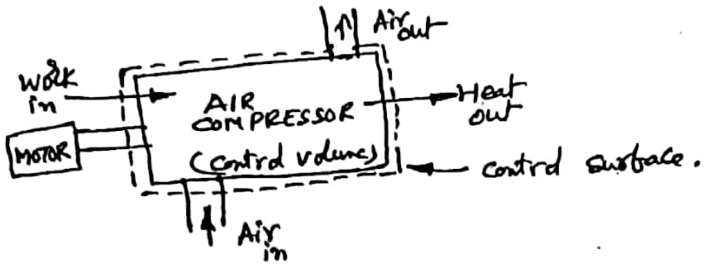
Type of thermodynamic system	Mass Transfer	Energy Transfer
1) closed	×	✓
2) open	✓	✓
3) Isolated	×	×.

Another Types of systems:-

① Homogeneous system:- A quantity of matter uniform throughout in chemical composition and physical structure is called a phase. Every substance can exist in any of the three phases i.e., solid, liquid and gas. A system consisting of a single phase is called a Homogeneous system.

② Heterogeneous system:- A system consisting of more than one phase is known as Heterogeneous system.

control volume For thermodynamic analysis of an open system such as an air compressor, attention is focussed on a certain volume in space surrounding the compressor known as the control volume bounded by a surface called control surface.



Thermodynamic properties, processes and A cycles:-

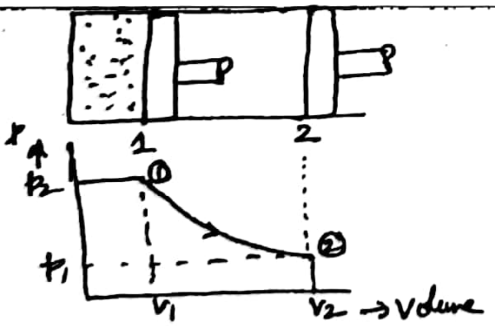
properties:- Every system has certain characteristics by which its physical condition may be described. Ex: volume, temperature, pressure such characteristics are called properties of the system.

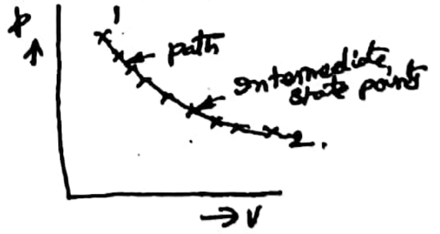
state:- state is a unique condition of system described at any instant of time described by its properties such as pressure, temperature, volume etc.,

Change of state:- Any operation in which one or more of the properties of a system changes is called a change of state.

path:- When a system undergoes change in its state, the line joining the series of intermediate states through which the system has passed is known as path.

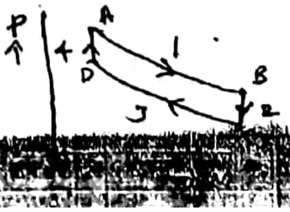
process:- When ~~a~~ the path is completely specified, the change of state is called a process. Ex: Isobaric process (pressure, P = const.)





Thermodynamic cycle (Cyclic process):-

If a system undergoes a series of processes from one state to another state and returns to its initial state by forming a complete cycle, then the system is said to be undergo a cyclic process. A cyclic process may have 2 (or) more than two processes.



Types of properties:-

1). **Intensive properties:-** Intensive properties ~~of~~ are those which are independant of the mass of the system.

Ex:- pressure, Temperature, density

2) **Extensive properties:-** Extensive properties are those which are dependant on the mass of the system.

Of the mass is increased, the values of Intensive properties are not changed. But the values of extensive properties also increases. Ex:- Total mass, Total volume, Total energy.

The extensive properties per unit mass, are intensive properties.

Ie., Volume ⟶ Extensive property

Specific Volume ⟶ Intensive property.

All specific extensive properties are intensive properties.

Ex:- specific volume, specific heat, Specific density.

MACROSCOPIC and MICROSCOPIC POINT OF VIEW:

Thermodynamic studies are undertaken by the following two different approaches.

	1. MACROSCOPIC approach (classical Approach)	2. MICROSCOPIC approach (Statistical Approach)
1.	In This approach, a certain quantity of matter is considered without taking into account The events occuring at molecular level. In otherwards, This approach to Thermodynamics is Concerned with overall behaviour. This is Known as Classical Thermodynamics.	The approach considers that The system is made up of a large no. of descrete particles known as molecules. These molecules have different Velocities and energies. The values of These energies are constantly changing with time. This approach to thermodynamics which is concerried directly with the structure of matter is known as Statistical Thermodynamics.
2.	The analysis of macroscopic system requires simple mathematical formulae.	The behaviour of the system is found by using statistical methods as the no. of molecules is very ~~to~~ large. So advanced statistical mathematical methods needed to explain changes in the system.

3.	The value of the properties of the system are their average values. For example consider a sample of gas in a closed container, the pressure of the gas is the average value of the pressure exerted by millions of individual molecules. The properties can be measured very easily. The change in properties can be felt by our senses.	The properties like, velocity, momentum, impulse etc, which describes the molecule can not be easily measured by instruments. our senses can not feel them.
4).	In order to describe a system, only few properties are needed	Large no-of variables are needed to describe a system, so the approach is completed.

* * *

Thermodynamic equilibrium:-

A system will be in a state of thermodynamic equilibrium, if ~~it~~ the conditions for the following three types of equilibrium are satisfied.

a). Mechanical Equilibrium b) chemical Equilibrium c) Thermal Equilibrium.

Mechanical Equilibrium:- If all the forces in the system and between the system and surroundings are balanced, then the system is said to be in mechanical equilibrium. This is possible only when pressure is same throughout the system and also equal to that of surroundings.

Chemical Equilibrium:- If no chemical reactions (or) transfer of matter takes place throughout the system, then the system is said to be in chemical equilibrium.

Thermal Equilibrium:- If the temperature is uniform throughout the system and between the system and surroundings, then the system is said to be in thermal Equilibrium.

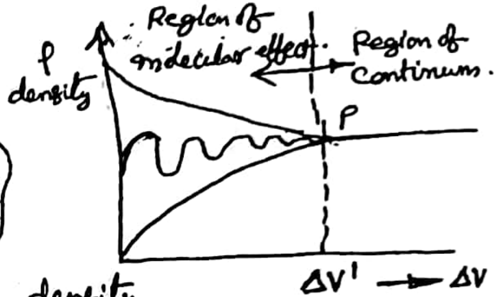
criteria for an Equilibrium.

Equilibrium	criteria
Thermal	Equilibrium of Temperature
Mechanical	Equilibrium of pressure and forces
Chemical	Equilibrium of chemical potential
Thermodynamic	All the above.

Concept of Continuum :-

To study about a system and its properties, it is always convient to consider the system as a continuous distribution of matter. This continuous distribution of matter is known as continuum. The concept of continuum is to treat the matter as continuous by disregarding the behaviour of individual molecules. In classical thermodynamics, The concept of continuum is very useful.

Let us consider the mass Δm in a volume ΔV surrounded the point P as shown in figure.



The ratio $\Delta m / \Delta V$ is the average mass density of the system with in the volume ΔV. The volume $\Delta V'$ is the smallest volume about the point P, for which the mass can be considered continuous. Any volume smaller than This volume will lead to discontinuity in the particles, atoms and electrons in the matter and the density becomes unpredictable.

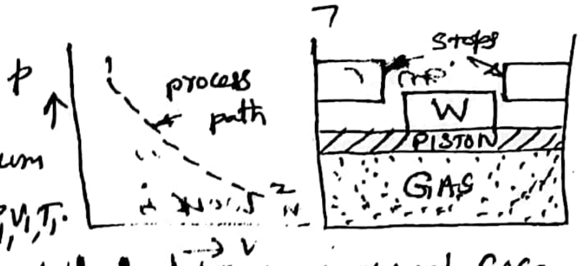
$$\rho \text{ density} = \lim_{\Delta V \to \Delta V'} \left(\frac{\Delta m}{\Delta V}\right).$$

Thus, continuum holds good from volume $\Delta V'$ and is non-continuum for a volume less than $\Delta V'$. This is due to the variation in the density of fluid from one point to another point with entering and leaving the molecules from the system in random manner.

Quasi-Static process

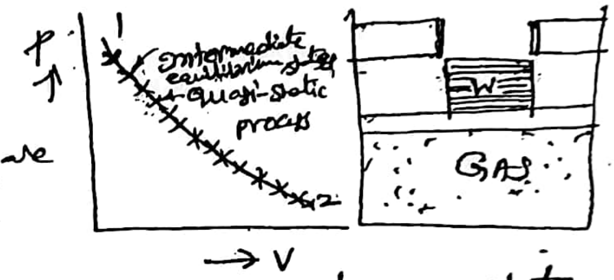
When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium states at all times, it is called a quasi-static or quasi-equilibrium process. A quasi-static process is viewed as a sufficiently slow process in which system changes its state very slowly under the influence of an infinitesimally small driving force. The system adjusts itself internally, so that the properties in one part of the system donot change any faster than those in the other part.

Let us consider a system of gas contained in a cylinder. The system is initially in equilibrium state, represented by properties p_1, V_1, T_1.



The weight (W) on the piston just ~~balances~~ the upward force exerted by the gas.

If the weight (W) is ~~removed~~, ~~the piston~~ will move up due to gas pressure. The system ~~again comes~~ to an equilibrium state by properties p_2, V_2, T_2. But the intermediate states passed through by the system are non-equilibrium states. Which can be described by points 1&2.



Now, if single weight W is made up of small pieces of weights and these weights are removed one by one very slowly from top of piston, the gas will pass through a series of equilibrium states.

If the mass are made negligibly small, the gas would undergo a quasi-equilibrium expansion process.

Classification of Thermodynamic processes:-

1. Non-flow processes. 2. Flow processes.

1. Non-flow processes:- The processes occur in closed system which dont permit the transfer of mass across their boundaries, are known as non-flow processes. Energy crosses the system boundary in the form of heat & work.

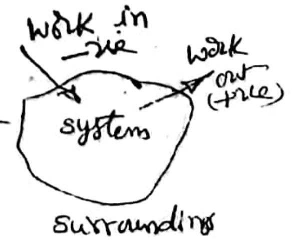
ex:- constant volume process, constant pressure process etc.

2. Flow processes:- The processes occuring in open system which permit the transfer of mass to and from the system are known as flow processes.

ex:- steady flow process through nozzles, turbines & compressors etc.

non-steady flow processes are filling (or) evacuation of vessels.

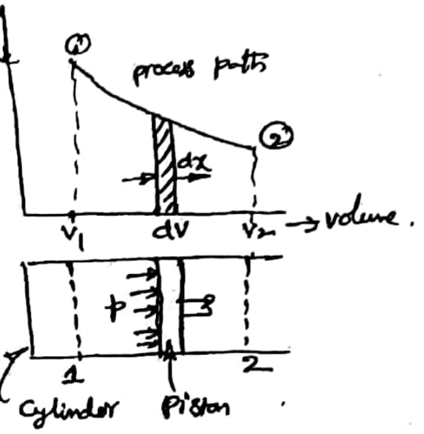
WORK:- work is transient quantity which only appears at the boundary while a change of state is taking place with in a system. units are Joules (J).



Sign convention:-

- → When work is done by the system, the sign is +ve.
- → When work is done on the system, the sign is -ve.

pdV work (or) [illegible] displacement work:-



Con[illegible] closed in a frictionless [illegible] cylinder arrangement.

Let the gas pressure is p, volume v and piston cross-sectional area is A. If the piston is allowed to move through a distance 'dx' in a quasi-equilibrium manner, the force applied on the piston is

F = pressure x cross-sectional area of piston = pA.

Then work transfer through the distance of dx, during the process, $\delta W = pAdx = pdV$.

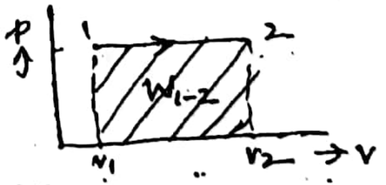
Total work transfer during a process is equal to area und p-v diagram.

$$\therefore \boxed{W = \int_1^2 pdV} \text{ KJ.}$$

Non flow work in various quasi-static processes

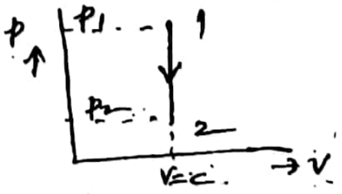
1). Constant pressure process (p=c) (or) $pv^0=c$.
(isochoric process)

$$W_{1-2} = \int_1^2 pdV = p[v_2 - v_1].$$



2) Constant volume process (or) Isochoric process (V=C); $pv^\infty=c$

$$W_{1-2} = \int_1^2 p\,dV = 0 \quad \left[\begin{array}{l}\text{Since} \\ V=\text{Constant} \\ dV=0.\end{array}\right.$$



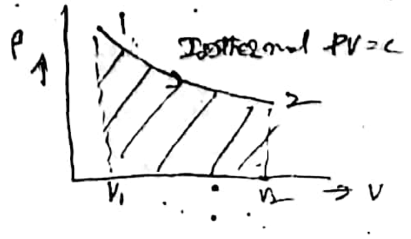
3) Constant temperature process (or) Isothermal process T=C (or) pv=c

$pv = p_1v_1 = p_2v_2 = c$

$$W = \int_1^2 pdv = \int_1^2 \frac{c}{V}dV = c\int_1^2 \frac{1}{V}dV$$

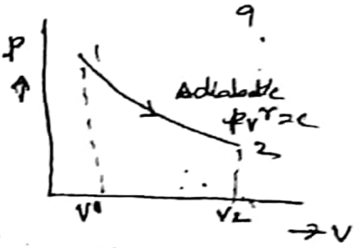
$$= c \ln V\Big]_1^2 = c \ln \frac{v_2}{v_1}$$

$$\therefore W = p_1v_1 \ln \frac{v_2}{v_1} = p_1 v_1 \ln \frac{p_1}{p_2}$$



Adiabatic process $pV^{\gamma}=c$

$p_1V_1^{\gamma}=p_2V_2^{\gamma}=c$



$$W=\int_1^2 p\,dV$$

$$=\int_1^2 \frac{c}{V^{\gamma}}\,dV=c\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2$$

$$=\frac{cV_2^{-\gamma+1}-cV_1^{-\gamma+1}}{-\gamma+1}=\frac{p_2V_2^{\gamma}\cdot V_2^{-\gamma+1}-p_1V_1^{\gamma}V_1^{-\gamma+1}}{-\gamma+1}$$

$$\therefore W=\frac{p_2V_2-p_1V_1}{-\gamma+1}\quad (\text{or})\quad =\frac{p_1V_1-p_2V_2}{\gamma-1}$$

polytropic process $pV^{n}=c$

$p_1V_1^{n}=p_2V_2^{n}=c$

$W=\int_1^2 p\,dV$, By solving.

$$W=\frac{p_1V_1-p_2V_2}{n-1}$$

A Gas in a closed system can undergo the following processes.

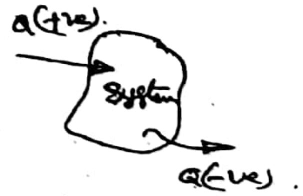
process	Law	Relation	Total Work (1-2)
1) constant pressure	$p=c$ (or) $pV^{0}=c$	$p_1=p_2=p_3$ at all state point	$W_{1-2}=p(V_2-V_1)$
2) constant volume	$V=c$ (or) $pV^{\infty}=c$	$V_1=V_2=V_3=$ "	$W_{1-2}=0$
3) constant temperature	$T=c$ (or) $pV^{1}=c$	$p_1V_1=p_2V_2=$ "	$W_{1-2}=p_1V_1\ln\frac{V_2}{V_1}$
4) Adiabatic	$pV^{\gamma}=c$	$p_1V_1^{\gamma}=p_2V_2^{\gamma}$ "	$W_{1-2}=\frac{p_1V_1-p_2V_2}{\gamma-1}$
5) polytropic	$pV^{n}=c$	$p_1V_1^{n}=p_2V_2^{n}$ "	$W_{1-2}=\frac{p_1V_1-p_2V_2}{n-1}$

Heat:- Heat is something which appears at the boundary when system changes its state due to a difference in temperature between the system and its surroundings. Symbol is Q.

Sign convention

→ When heat flows into the system, Q is +ve

→ When heat flows from (or) out of system, Q is -ve



PROBLEMS

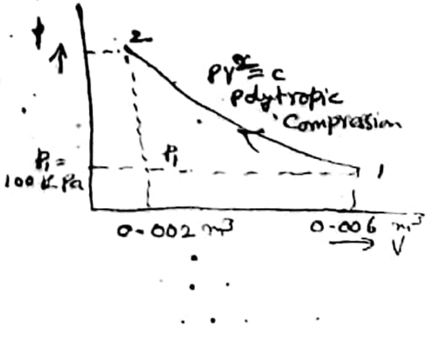
① If a gas of volume 6000 cm³ and at a pressure of 100 kPa is compressed quasistatically to $PV^{x}=c$ until the volume becomes 2000 cm³. Calculate the final pressure and work transfer.

Given data:-

$p_1=100\text{ kPa}=1\text{ bar}=10^5\text{ N/m}^2$

$V_1=6000\text{ cm}^3=0.006\text{ m}^3$

$V_2=2000\text{ cm}^3=2000\times10^{-6}=0.002\text{ m}^3.$



Final pressure (p_2)

we know that for polytropic process, $pV^2 = c = p_1V_1^2 = p_2V_2^2$.

$$\therefore p_2 = p_1 \left(\frac{V_1}{V_2}\right)^2 = 1\left(\frac{0.006}{0.002}\right)^2 = 9 \text{ bar}.$$

Workdone (W_{1-2}): polytropic compression

we know that $W = \int_{V_1}^{V_2} p\,dv = \frac{(p_2V_2 - p_1V_1)}{n-1}$ for polytropic process.

$$= \frac{(9 \times 0.002 - 1 \times 0.006)}{2-1} \times 100 \text{ KJ}.$$

workdone, $W = 1.2$ KJ Ans. ✓

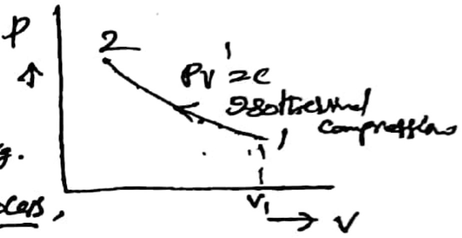
② A mass of 2.5 kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa for which PV = constant. The initial volume is 0.8 m³/kg. Find the workdone by the piston to compress the air.

Sol:- mass, $m = 2.5$ kgs.

$p_1 = 0.1$ MPa

$p_2 = 0.7$ MPa

process, $pV = c$; $v_{s1} = 0.8$ m³/kg.



we know that workdone in $PV = C$ process,

$$W = p_1V_1 \ln\left(\frac{V_2}{V_1}\right) = p_1V_1 \ln\frac{p_1}{p_2}$$

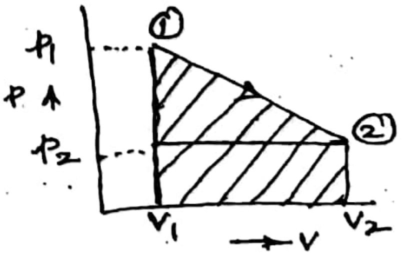
$$= 0.1 \times 10^3 \times 2 \ln\frac{0.1}{0.7}$$

$W = -389.182$ KJ ✓

Since V_1 = specific vol × mass $= 0.8 \times 2.5 = 2$ m³.

③ An engine cylinder has piston of area 0.12 m² and contains gas at a pressure of 1.5 MPa. The gas expands according to a process which is represented by a straight line on a p-v diagram. The final pressure is 0.15 MPa. Calculate the W.D by the gas on the piston if the stroke is 0.3 M

Sol:- Given, Area of piston $= 0.12$ m²



initial gas pressure, $p_1 = 1.5$ MPa

Final gas pressure, $p_2 = 0.15$ MPa

Length of stroke, $L = 0.3$ metres.

stroke volume, $(V_2 - V_1)$ = Area of piston (or) cylinder × stroke length

$= 0.12 \times 0.3 = 0.036$ m³.

∴ workdone on the piston is equal to shaded Area in p-v diagram.

$$W = \frac{1}{2}(p_1 - p_2)(V_2 - V_1) + p_2(V_2 - V_1)$$

$$= \frac{1}{2}(1.5 - 0.15) \times 10^6 (0.036) + 0.15 \times 10^6 \times 0.036$$

$W = 0.0297 \times 10^6$ Joules. $= 29.7$ KJ ✓

PROB. A gas undergoes a reversible non-flow process according to the relation $p = (-3V+15)$ where V is the volume in m^3 and p is the pressure in bar. Determine the workdone when the volume changes from 3 to 6 m^3.

SOL. pressure, $p = (-3V+15)$

Initial volume, $V_1 = 3\ m^3$

Final volume, $V_2 = 6\ m^3$

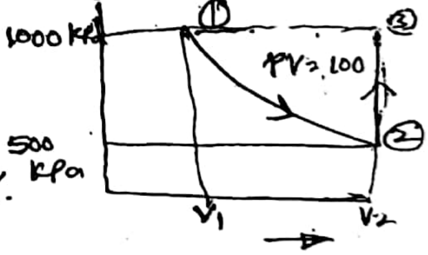
We know, Workdone $= \int_1^2 p\,dV = \int_1^2 (-3V+15)\,dV$

$$= -3\cdot\frac{V^2}{2} + 15\Big]_3^6 = -1.5\,(6^2-3^2) + 15\,(6-3)$$

$$= -40.5 + 45 = 4.5\times10^5 \text{ Joules. } [\because p \text{ in bar } 10^5]$$

$W = 450$ KJ.

PROB. A gas expands according to the equation $pV = 100$, where p is the pressure in KPa and V is the specific volume in m^3/kg. The initial pressure of gas is 1000KPa and final pressure is 500 KPa. The gas is then heated at constant volume back to its original pressure of 1000 KPa. Determine the work of combined process. Also sketch the process on p-V co-ordinates.



SOL. $pV = 100$

Initial pressure, $p_1 = 1000\ KN/m^2$

At state 2 pressure, $p_2 = 500\ KN/m^2$

At state 3, Final pressure, $p_3 = p_1 = 1000\ KN/m^2$.

Workdone during 1-2 process (constant temperature i.e process)

We know, $pV = 100 \Rightarrow p_1V_1 = p_2V_2$

$V_1 = \frac{100}{1000} = 0.1\ m^3/kg \qquad V_2 = \frac{100}{500} = 0.2\ m^3/kg$.

$W_{1-2} = p_1V_1 \ln\frac{V_2}{V_1} = 1000\times0.1\times\ln\frac{0.2}{0.1} = 69.315\ KJ/kg$

Workdone during 2-3 process (constant volume process $V = C$).

$W_{2-3} = 0$, since 2-3 process line is vertical.

$\therefore W_{1-3} = W_{1-2} + W_{2-3} = 69.315\ KJ/kg$

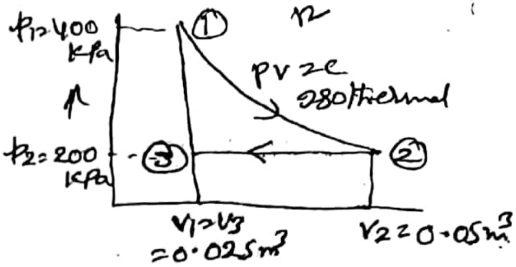
PROB. A gas undergoes two processes that are in series. The first process is an expansion process that is carried out according to the law $pV = c$ and the second process is a constant pressure process that returns to the gas to the initial volume of the first process. The start of first process is at 400 KPa and 0.025 m^3 with an expansion to 200 KPa. Sketch the process. p-V diagram and determine the work of the combined process.

SOL. $pV = C$

$p_1 = 400$ KPa

$V_1 = 0.025\ m^3$

$p_2 = 200$ KPa



We know that $pV = C = p_1V_1 = p_2V_2$

$$\therefore V_2 = \frac{p_1}{p_2} \times V_1 = \frac{400}{200} \times 0.025 = 0.05\ m^3$$

Workdone during isothermal process, T=C (or) PV=C (1-2) process

$$W_{1-2} = p_1V_1 \ln\frac{p_1}{p_2} = 400 \times 0.025 \ln\frac{400}{200} = 6.93\ KJ$$

$$W_{2-3} = p_2(V_3 - V_2) = 200(0.025 - 0.05) = -5\ KJ.$$

$\therefore$ Networkdone $W_{1-3} = W_{1-2} + W_{2-3} = 6.93 - 5 = 1.93$ KJ

Prob In a reversible non-flow process, the work is done by a substance in accordance with $V = \frac{2.80}{p}\ m^3$, where p is pressure in bar. Find the workdone (or) by system as pressure increases from 0.7 bar to 7 bar.

SOL. A reversible non flow process with

$p_1 = 0.7$ bar $= 70$ KPa, $p_2 = 7$ bar $= 700$ KPa.

$V = \frac{2.80}{p}\ m^3$;

To find: work interaction by the system,

Analysis: The initial and final volume of working substance, $V_1 = \frac{2.80}{p_1} = \frac{2.80}{0.7} = 4\ m^3$.

$$V_2 = \frac{2.80}{p_2} = \frac{2.8}{7} = 0.4\ m^3$$

For a given relation, pressure p can be expressed as

$$p = \frac{2.80}{V}\ \text{bar} = 100 \times \frac{2.8}{V}\ \text{kPa}$$

The workdone by a system can be calculated as

$$W = \int_1^2 p\,dV = 100 \times 2.8 \times \int_4^{0.4} \frac{1}{V}\,dV$$

$$= 280 \times \ln V\Big]_4^{0.4} = 280 \ln\left(\frac{0.4}{4}\right)$$

$$W = -644.7\ KJ$$

Prob In a piston-cylinder arrangement, the pressure is inversely proportional to the square ~~root~~ of the volume. The initial pressure is 10 bar in the cylinder and the initial volume is 0.1 m³. The volume is now changed so that the final pressure is 2 bar. Find the workdone in KJ.

SOL. The relation $p \propto \frac{1}{V^2}$

$p_1 = 10$ bar $= 1000$ KPa

$V_1 = 0.1\ m^3$

$p_2 = 2$ bar $= 200$ KPa.

To find: workdone during the process

Analysis: The given relation

$$p \propto \frac{1}{V^2} \text{ (or) } p = \frac{K}{V^2}$$

At state 1, $p_1 = \frac{K}{V_1^2}$, where K is constant of proportionality.

$$K = p_1V_1^2 = (1000\ \text{KPa}) \times (0.1\ m^3)^2 = 10\ \text{KPa} \cdot m^6.$$

Now at state 2,

$$p_2 = \frac{K}{V_2^2} \Rightarrow V_2 = \sqrt{\frac{K}{p_2}} = \sqrt{\frac{10}{200}} = 0.223\ m^3.$$

Now, the workdone during the process,

$$W = \int_1^2 p\,dV = \int_1^2 \frac{K}{V^2}\,dV$$

$$= K\left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$

$$= 10 \times \left[\frac{1}{0.1} - \frac{1}{0.223}\right]$$

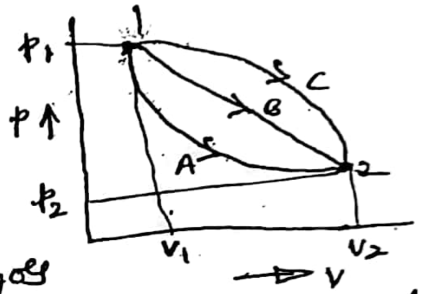
$$= 57.1\ KJ.$$

* path function and point function

① path function:- The function which depends on the path of system passed and not on the end states is known as path function.
Example:- Work transfer, Heat Transfer.

② point function:- The function which depends on the end states not on the path of the system is known as point function.
Example:- property of system i.e., volume, temp, pressure etc.

'properties' are point functions:-



Thermodynamic properties are point functions. since for a given state, There is a definite value for each property. when a system undergoes a change from one state to another, the properties of the system also changes, which depends only on end states and not on the path followed between These two states. Therefore, These properties are called state functions (or) point functions. point functions can be represented by a point ~~on~~ on any plot eg., Temperature, pressure, volume etc., These properties have exact differentials designated by d (symbol). Therefore change in volume (or) pressure represented by dV (or) dP.

The differentials of point functions are exact (or) perfect differentials, and the integration is simple

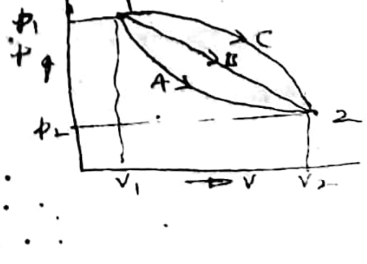
$$= \int_{V_1}^{V_2} dV = V_2 - V_1.$$

→ The change in volume this depends only on the end states of the system irrespective of the path followed.

→ For a cyclic process, the initial and final states of the system are the same and hence change in any property is zero. $\oint dV = 0$, $\oint dp = 0$, $\oint dT = 0$.

WORK TRANSFER - 'PATH' FUNCTION

A quantity whose value depends on the particular path followed during the process is called a path function.



It requires a particular path and direction to represent the quantity on any plot. e.g., heat, work etc.

With reference to figure, it is possible to take a system from state 1 to state 2 along many quasi-static paths such as A, B, C.

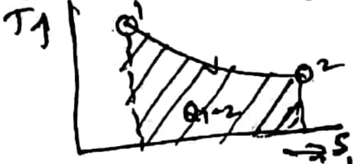
Since the area under the each curve represents the work for each process, the amount of work involved in each case is not a function of the end states of the process and it depends on the path, the system follows in going from state 1 to state 2.

The path functions have inexact differentials represented by the symbol δ. Therefore, a differential amount of work (or) heat is written by δW (or) δQ.

HEAT TRANSFER - A 'PATH' FUNCTION :-

Heat transfer is a path function, that is the amount of heat transferred when a system changes from state ① to ② depends on the intermediate states through which the system passes. i.e., its paths. Therefore δQ is an inexact differential and we write

$$\int_1^2 \delta Q = Q_{1-2}$$



path function	point function
1. If the change in function depends on the path followed by a system then that function is called path function	1. If the change in function depends only on initial and final state of process, then that function is called point function.
2. The function depends on path followed by the system.	2. This function does not depend on path followed by the system.
3. Examples:- work, energy (heat) etc.	3. Example, pressure, volume, temp, (thermodynamic properties)
4. The differentials of path functions are inexact (or) imperfect differentials	4. The differentials of point functions are exact (or) perfect differentials
5. This function does not satisfy the equation $dz = Mdx + Ndy$	5. This function satisfies $dz = Mdx + Ndy$

PROB A gas contained in a piston cylinder arrangement expands from 0.75 m³ volume to 1.25 m³ volume until the pressure remains constant at 200 kPa. If the gaseous system receives 80 kJ of work from a paddle wheel, determine net work done by the system.

SOL Given, $V_1 = 0.75\ m^3$, $V_2 = 1.25\ m^3$

$p_2 = p_1 = 200\ kPa$.

paddle wheel work $= -80\ kJ = W_1$ (work supplied).

Take, $W_2 =$ work done by the system $= \int_{V_1}^{V_2} p\,dV = p(V_2 - V_1)$

$W_2 = 200 \times 10^3 [1.25 - 0.75] = 100\ kJ$. (+ve)

∴ Net work done, W.D $= W_1 + W_2 = -80 + 100 = 20\ kJ$ (+ve).

PROB A vacuum gauge connected to a tank reads 30 kPa at a location where the barometer reads 755 mm of Hg. Calculate the absolute pressure in the tank assuming the density of Hg (mercury) to be 13,590 kg/m³.

SOL. Vacuum gauge reading, $p_v = 30 \times 10^3$ Pa

density of mercury, $\rho = 13{,}590\ kg/m^3$.

∴ We know that, vacuum pressure, $p_v = \rho g h$.

$30 \times 10^3 = 13{,}590 \times 9.81 \times h$.

~~vacuum gauge height, ∴ h = $\frac{30 \times 10^3}{13{,}590 \times 9.81}$ = 0.225 m of Hg~~

$= 225$ mm of Hg.

∴ Absolute pressure = Barometric pressure − Vacuum gauge pressure

$= 755 - 225 = 530$ mm of Hg.

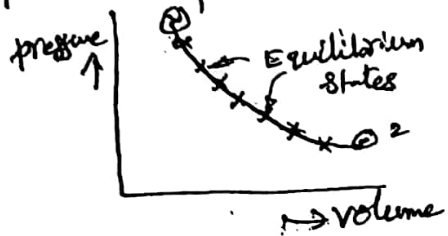
Differences:

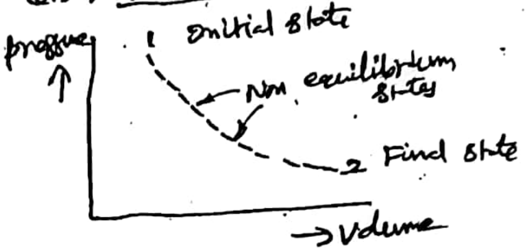
Adiabatic process & isentropic process, Differences.

Adiabatic process:- In an adiabatic process, the gas changes its condition without the transfer of heat to (or) from the surroundings: pressure, volume and temperature of the gas may vary during an adiabatic process. During an adiabatic process, no heat is transferred to the gas from an external source and the gas must do the external work at the expense of its own energy. An adiabatic expansion is always accompanied by a decrease in the temperature of the gas as the gas gives up its own internal energy to do work

Isentropic process:- A reversible (Q1-2 = 0) adiabatic process is called isentropic process.

<u>Reversible process</u>: If the process is assumed to take place sufficiently slowly so that the deviation of the properties at the intermediate states is infinitesimally small, Then every state passed through by the system will be in equilibrium. Such a process is called quasi-static (or) <u>reversible process</u>.





<u>Irreversible process</u>:- If the process takes place in such a manner that the properties at the intermediate states are not in equilibrium state (except the initial and final state), then the process is said to be non-equilibrium (or) irreversible process. This process is represented by broken line on the property diagram.

All the processes occuring in nature are irreversible. When these processes are reversed, They cannot return to their initial state of the system without changing the surroundings.

* <u>Irreversibility</u>:- When any actual process occurs, it produces certain effects, therefore, the process can not be reversed and the system and its surroundings can not be restored to their initial states. During an irreversible process, the total energy remains constant but capacity to do work is lost due to degradation of some portion of available energy.

This degradation of energy is responsible for entropy generation with in the system during a process. The entropy generation is always equal to irreversibilities involved in the process.

∴ Irreversibility, $I = W_{max} - W_{useful}$ (KJ).

* <u>Causes of Irreversibility</u>:- Irreversibility of the process may be caused due to
(1) Mechanical (or) thermal irreversibility
(2) Internal and External irreversibility.

(i) Mechanical Irreversibility:- Is associated with friction. When two bodies have relative movement, a frictional force opposes the motion at the interface of these two bodies and some work is lost to overcome this friction. When direction is reversed, some work is further required to overcome friction. Friction is also involved between solid and fluid, & layers of fluid due to different velocities.

(ii) Thermal Irreversibility:- Is associated with transfer of heat due to finite temperature difference between a system and its surroundings. An amount of heat lost from a system during compression can not be regained during expansion process causes irreversibility.

(iii) Internal Irreversibility:- Is also caused due to mixing of different layers of fluid at different temperatures. It is also due to free (or) unrestrained expansion of fluid.

(iv) External Irreversibility:- is associated with friction at bearings and friction between atmospheric air and rotating members.

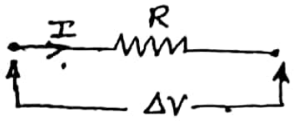
*Conditions for a Reversible process:-

1) The process should not involve friction of any kind.
2) Heat Transfer should not takes place due to finite temperature difference between system and surroundings.
3) There should not be a mixing of fluid layers at different temperatures.
4) There should not be free and unrestrained expansion
5) The process must pass through a series of equilibrium states.

* Forms of Work Transfer (Other Types of Work Transfer):-

There are forms of work other than pdV (or) displacement work. The following are the additional types of work transfer which may get involved in system - surroundings interactions.

① Electrical work:-



Resistance heating as electrical work.

Electrical work is the energy interaction due to crossing of electrons at the system boundary. In an electric field, the electrons in a wire move under the effect of electromotive forces for doing work [Driving a motor, fan etc.]. The resistance heating as an electrical work shown in figure.

Rate of electrical work transfer

$$\dot{W}_E = VI \text{ watts}.$$

The work done W_E in time Δt is, $W_E = VI\Delta t$ (Joules).

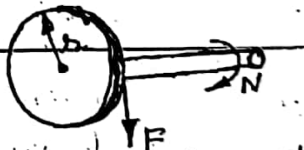
② MECHANICAL WORK:-

In mechanics, the work done by a system is expressed as a product of force (F) and displacement (S).

$$W = FS.$$

If force is not constant, the work done is obtained by adding the differential amounts of work, $W = \int_1^2 F\,ds$.

③ SHAFT WORK:-



Work of a moving shaft

The shaft work is the work associated with energy transmission with a rotating shaft. It is the product of torque (product of force and radius of shaft) and angular displacement.

$$\text{Torque}, T = F \times r \quad \text{or} \quad F = \frac{T}{r}$$

This force acts through a displacement per unit time,

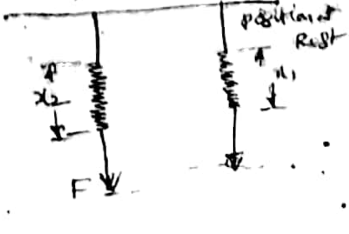
$$S = 2\pi r \times \frac{N}{60}.$$

Shaft work per unit time, $W_{shaft} = Fs = 2\pi r \times \frac{N}{60} \times \frac{T}{r}$.

$$\boxed{W_{shaft} = \frac{2\pi NT}{60}} \text{ watts}.$$

④ Spring work:-

Elongation of spring under Force



When force is applied on a spring, its length changes.

If dx is change in The length of a spring under The influence of a force F, then the workdone by the spring is

$$\delta W_{spring} = F dx.$$

where The force F exerted can be defined in terms of spring constant. K(N/m) as.

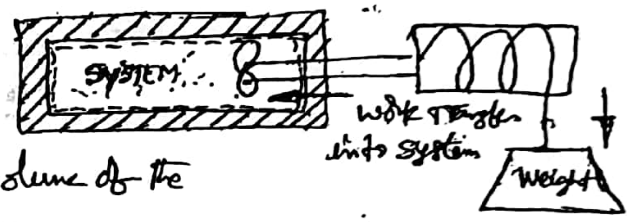
$$F = Kx, \text{ Newtons}.$$

Then spring work $\delta W = Kx\,dx$.

If spring length changes from x_1 to x_2

$$\therefore \boxed{W_{spring} = K\int_{x_1}^{x_2} x\,dx = \frac{1}{2}K(x_2^2 - x_1^2)}$$

paddle wheel work (or) stirring work:



As the weight is lowered and the paddle wheel turns, there is work transfer into the fluid system which gets stirred. Since the volume of the system remains constant $\int p\,dv = 0$.

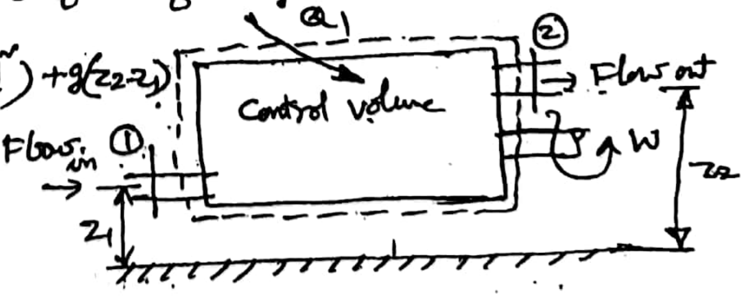
If m is the mass of the weight lowered through a distance dz and T is the torque transmitted by the shaft in rotating through an angle dθ, the differential work transfer to the fluid is

$$dW = mg\,dz = T\,d\theta.$$

$$\text{total work transfer, } W = \int_1^2 mg\,dz.$$

Flow work (or) Flow energy:- refers to work required to push a certain mass of fluid into and out of the control volume. A flow process constitutes an open system, in which the working substance enters and leaves the control surface of a system.

$$q_{1-2} - W_{1-2} = (h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1)$$



HEAT:- It is a transfer form of energy that flows between two systems (or a system and its surroundings) by virtue of the temperature difference between them. The temperature difference is the potential for heat transfer. Therefore There would be no heat transfer between two systems if they are at the same temperature.

The amount of heat transferred from the state 1 to the state 2 is designated by Q_{1-2} (or) Q and it is measured in Joules (or) Kilo Joules (KJ).

Heat transfer per unit mass of a system is defined by

$$q = \frac{Q}{m} \; (KJ/kg).$$

The heat (or) heat energy is generally referred to as heat transfer.

The transfer of heat into a system is called heat addition (or) heat supply

The transfer of heat from the system is called heat rejection.

Similarities between Heat and Work

1. Both are recognized at the boundary of the system as they cross it, thus both heat and work are boundary phenomena.
2. A system may have energy, but not heat (or) work because, heat and work are transient phenomena.
3. Both are associated with a process, not a state. Therefore, unlike properties heat (or) work has no meaning at a state.
4. Both are path functions. They are represented by a path followed during the process.
5. The equations for heat and work transfer can not be differentiated exactly. The differential quantities of heat and work are represented by as δQ and δW, respectively.

Dissimilarities between Heat and Work transfer

1. Heat is a low-grade energy, where as The work is a high grade energy.
2. Heat transfer takes place due to temperature difference only, while work transfer may take place due to any potential difference in pressure, voltage, height, velocity and temperature etc.,
3. A stationary system can not do work, while such a restriction is imposed on heat transfer.
4. The entire quantity of work can be converted into heat (or) any other form of energy, while conversion of the entire quantity of heat into work is not possible
5. Conversion of work into heat (or) any other form of energy is possible with a single process, while conversion of heat into work requires a complete cyclic process, like a steam power plant.

Q.B UNIT-1

PROB Explain thermodynamic system, surroundings and Universe, illustrate the same with examples.

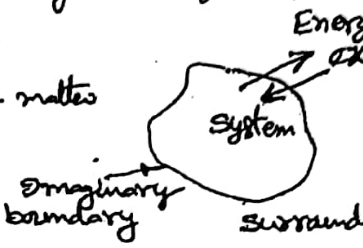
Sol: Thermodynamic system:- A thermodynamic system (or) simply a system is defined as a certain quantity of matter (or) a prescribed region in space considered for thermodynamic study (or) we focus our attention to study its properties. The study also involves changes in properties due to exchange of energy in the form of heat and work. The system may be a quantity of steam, a mixture of vapour and gas (or) a piston-cylinder assembly of an I.C engine and its contents.

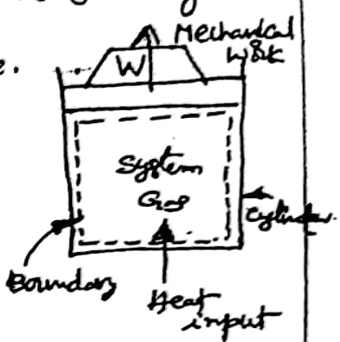
For the description of a thermodynamic system, some of the following quantities need to be specified.

(i) quantity as well as composition of matter

(ii) measurable properties such as pressure, temp and volume of the system.

(iii) Energy of the system.





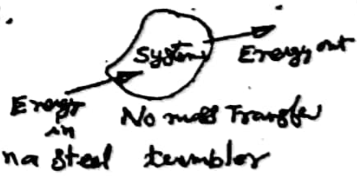
Surroundings: The region outside the system is called the surroundings (or) environment.

Boundary:- The real (or) imaginary surface that separates the system from its surroundings is called the boundary. The boundary may be fixed (or) movable. The boundary may change shape, volume, position and (or) orientation with respect to observer. For example, an elastic ballon changes in shape & volume during a certain process.

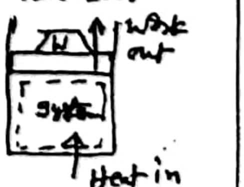
Universe:- System plus surroundings put together is known as universe. Hence it has no boundaries and is of infinite size.

PROB Distinguish between closed system, open system & isolated system with suitable examples.

Sol. ① closed system:- on a closed system, the mass is fixed. There is no mass transfer across the boundaries but energy transfer may takes place into (or) out of the system.

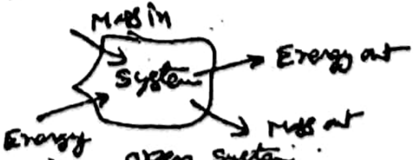


Ex:- i) Heating the gas in a cylinder ii) Hot coffee in a steel tumbler iii) steam power plant etc.



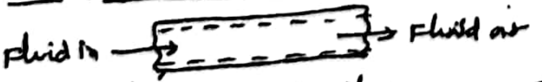
Closed system

② Open system:- On an open system both mass and energy crosses the boundary.

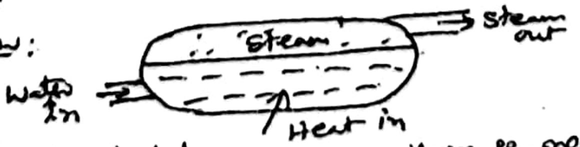


open system

Ex:- flow through tubes & Nozzles:

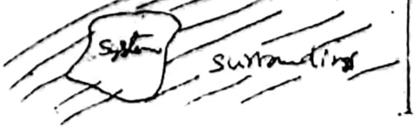


Water tube boiler:

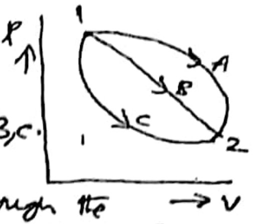


③ Isolated system:- On isolated system, there is neither energy transfer nor mass transfer occurs across the boundaries. Not having any interaction with surroundings.

Ex:- 1) Thermo flask 2) Insulated Chamber.

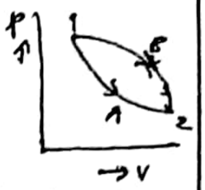


PROB Show that Work is a path function and not a state function

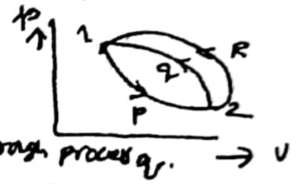


SOL: Work is a path function and not a state function. This can be proved with the help of the p-v diagram.
On the p-v diagram, a system is at state 1. To move the system from state 1 to 2, it can follow any path such as A, B, C. etc. The area under the curve represents the work done.
Here the area under the each curve is not equal to even though the initial and final states are same. From this, we can conclude that work is a path function and not a state function.

PROB Justify the statement that Work and heat are not properties.



SOL: Consider a volume of (V) gas enclosed in a piston cylinder assembly as shown in figure. If the gas is allowed to expand by changing its pressure from P_1 to P_2. Increase in volume of the gas causes the piston to move outwards and hence work is done by the gas. The expansion of the process from P_1 to P_2 is plotted on P-V diagram. Now, if the gas initially was allowed to expand by a different process, say B., it would have followed the path 1B2. Therefore, it makes us clear that workdone by the gas while following path 1A2 is different from that of path 1B2 as both processes follow different paths. Hence, it can be said that work is not a point function but a path function. The differential of path function is inexact and hence workdone should be written as δW instead of dW.



Heat is a path function:- Consider a system of gas in a piston cylinder arrangement. Let the gas be taken to a state 2 from state 1 to 2 through process P and back to initial state through process Q. The gas can also be taken to initial state by another process R.

Apply first law to both cycles [1P2Q1, 1P2R1]

$$\int_{1P2}\delta Q+\int_{2Q1}\delta Q-\int_{1P2}\delta W-\int_{2Q1}\delta W=0 \quad \text{—①}, \qquad \int_{1P2}\delta Q+\int_{2R1}\delta Q-\int_{1P2}\delta W-\int_{2R1}\delta W=0 \quad \text{—②}$$

Substracting 2 in equation 1,

$$\int_{2Q1}\delta Q-\int_{2R1}\delta Q-\left[\int_{2Q1}\delta W-\int_{2R1}\delta W\right]=0$$

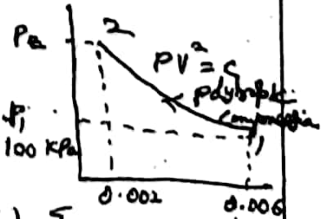
We know work is a path function

Hence $\int_{2Q1}\delta W-\int_{2R1}\delta W\neq 0$

Similarly $\int_{2Q1}\delta Q-\int_{2R1}\delta Q\neq 0$

$\therefore \int_{2Q1}\delta Q\neq\int_{2R1}\delta Q$ ∴ Heat is path function not point function.

PROB. If a gas of volume 6000 cm³ and at a pressure of 100 KPa, is compressed quasi-statically to PV^2 = constant until the volume becomes 2000 cm³. Calculate the final pressure & work transfer.



SOL. $P_1 = 100\text{ KPa} = 1\text{ bar} = 10^5\text{ N/m}^2$

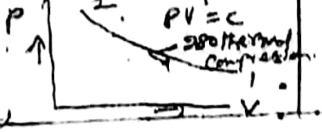
$V_1 = 6000\text{ cm}^3 = 0.006\text{ m}^3$; $V_2 = 2000\text{ cm}^3 = 0.002\text{ m}^3$.

Final pressure (P_2): $PV^2 = P_1V_1^2 = P_2V_2^2$.

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^2 = 1\left(\frac{0.006}{0.002}\right)^2 = 9\text{ bar}.$$

Workdone (W_{1-2}): $\int_{V_1}^{V_2} P\,dV = \frac{P_2V_2-P_1V_1}{n-1} = \frac{(9\times0.002-1\times0.006)}{2-1}\times10^5 = 1{,}200\text{ J}$
$= 1.2\text{ KJ}$

PROB. A mass of 2.5 Kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa for which PV = constant. The initial volume is 0.8 m³/kg. Find the workdone by the piston to compress the air.



SOL. mass, m = 2.5 Kgs, $P_1 = 0.1\text{ MPa} = 0.1\times10^6\text{ Pa}$; $P_2 = 0.7\times10^6\text{ Pa}$
isothermal process; $v_{s1} = 0.8\text{ m}^3/\text{kg}$; $V_1 = m\times v_{s1} = 0.8\times2.5 = 2\text{ m}^3$

Work, $W_{1-2} = P_1V_1 \ln\frac{V_2}{V_1} = P_1V_1\ln\frac{P_1}{P_2}$

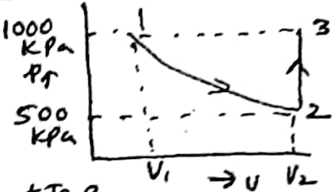
(Contd. 3rd page)

Workdone in isothermal process, $W_{1-2} = p_1 V_1 \ln \frac{p_1}{p_2} = 0.1 \times 10^6 \times 2 \ln \frac{0.1 \times 10^6}{0.7 \times 10^6}$

$= -389,182\ J = -389.182\ kJ$

PROB A gas expands according to the equation $pv = 100$, where p is the pressure in KPa and v is the specific volume in m^3/kg. The initial pressure of the gas is 1000 KPa and final pressure is 500 KPa. The gas is then heated at constant volume back to its original pressure of 1000 KPa. Determine the work of combined process. Also sketch on p-v co-ordinates.

SOL $pv = 100$; Initial pressure, $p_1 = 1000\ KN/m^2$



At state 2, pressure, $p_2 = 500\ KN/m^2$, At state 3, final pressure, $p_3 = p_1 = 1000\ KN/m^2$

Workdone during (1-2) process $pv = 100 = p_1 v_1 = p_2 v_2$ (Constant Temp. process)

$p_1 v_1 = 100$; $v_1 = \frac{100}{1000} = 0.1\ m^3/kg$; $v_2 = \frac{100}{500} = 0.2\ m^3/kg$.

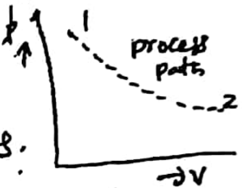
$W_{1-2} = p_1 v_1 \ln \frac{v_2}{v_1} = 1000 \times 0.1 \ln \frac{0.2}{0.1} = 69.315\ kJ/kg$.

Workdone (W_{2-3}) during (2-3) constant volume process, $W_{2-3} = 0$.

∴ total workdone, $W_{1-3} = W_{1-2} + W_{2-3} = 69.315 + 0 = 69.315\ kJ/kg$.

PROB Explain about quasi-static process.

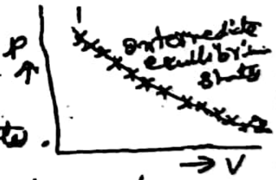
SOL When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium states at all times, it is called quasi-static (or) quasi-equilibrium process.



Let the gas initially at properties $p_1 v_1 T_1$. The weight just balances on piston with upward force by gas.

If the weight (W) is removed, piston will move upwards and attains equilibrium state with properties $p_2 V_2 T_2$. The intermediate states are non-equilibrium states.

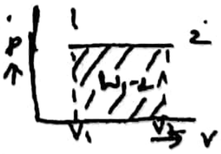
Now, if the single weight (W) is made up of small pieces of weights and these weights are removed one by one slowly from the top of piston, The gas will pass through a series of equilibrium state. If masses are very small, the gas would undergo quasi-equilibrium expansion process.



Quasi-static work in a closed system.

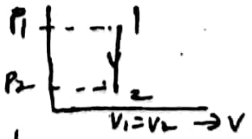
1) Constant pressure process ($p = c$) ;

$W_{1-2} = \int_1^2 p\,dv = P[V_2 - V_1]$



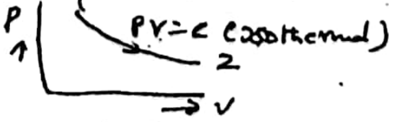
2) Constant volume process ($V = C$)

$W_{1-2} = \int_1^2 p\,dV = 0$ since $dv = 0$



3) Constant temperature process ($T = C$)

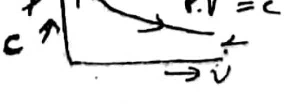
$PV = C = p_1 V_1 = p_2 V_2$



$W_{1-2} = \int p\,dv = \int \frac{c}{V} dv = c \int \frac{1}{v} dv$

$= P_1 V_1 \ln \frac{V_2}{V_1} = P_1 V_1 \ln \frac{P_1}{P_2} = mRT_1 \ln \frac{P_1}{P_2}$

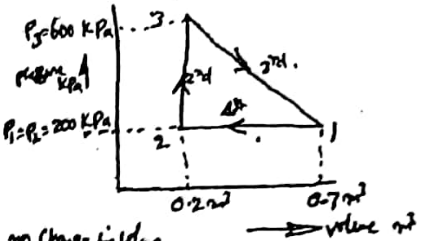
4) Adiabatic process $PV^{\gamma} = C$, $P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = PV^{\gamma} = C$



$W_{1-2} = \int_1^2 P\,dV = \int_1^2 \frac{C}{V^{\gamma}} dV = C \left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2$

$= \frac{C \cdot V_2^{-\gamma+1} - C \cdot V_1^{-\gamma+1}}{-\gamma+1}$, $\left(\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}\right) = \left(\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}\right) = \frac{mR(T_1 - T_2)}{\gamma - 1}$

PROB A cycle consists of three processes. The first is constant pressure compression at 200 KPa from an initial volume of 0.7 m^3 to a final volume of 0.2 m^3. The second process takes place at constant volume with pressure increasing to 600 KPa. The third process to the beginning of the first process. Sketch the cycle on P-V co-ordinates and calculate the net work transfer.



SOL process (1-2) :- Constant pressure compression process.

$p_1 = p_2 = 200$ KPa ; $V_1 = 0.7 m^3$ & $V_2 = 0.2 m^3$

∴ Work done on the system, $W_{1-2} = p_1[V_1 - V_2] = 200[0.7 - 0.2] = 100$ KPa. (−ve)

process (2-3) :- Constant volume compression process, $W_{2-3} = 0$ [Since $PdV = 0$, no change in volume during the process 2-3].

process (3-1) :- Expansion process follows straight inclined line from 3 to 1.

$W_{3-1} = \frac{1}{2}(p_3 - p_1)(V_1 - V_3) = \frac{1}{2}[600 - 200][0.7 - 0.2] = 100$ KPa (+ve) since process 3-1 is expansion process

∴ Total workdone, $W = W_{1-2} + W_{2-3} + W_{3-1} = -100 + 0 + 100 = 0$.

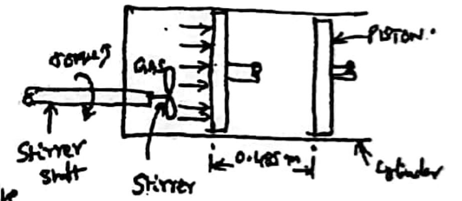
PROB A fluid contained in a horizontal cylinder fitted with a frictionless leakproof piston, is continuously agitated by means of stirrer passing through cylinder cover. The cylinder diameter is 0.4 m. During the stirring process lasting 10 minutes, the piston slowly moves out a distance of 0.485 m against the atmosphere. The net workdone by the fluid during the process is 2 KJ. The speed of the electric motor driving the stirrer is 840 rpm. Determine the torque in shaft and power output of the motor.

SOL.

① Paddle work (−ve work) because work is done by stirrer on fluid system, $W_p = 2\pi NT \times 10$

$= 2 \times 3.141 \times 840 \times T \times 10$ (−ve) work

$= 52,768\ T$ Joules



② Displacement work (+ve) piston moves right side (outwards) work is positive

$W_p = W_d = p \cdot pAl = 1.01325 \times 10^5 \times \frac{\pi}{4}(0.4)^2 \times 0.485 = 6174.2$ Joules.

③ Net workdone by the fluid, $W_{net} = 2$ KJ $= 2000$ Joules.

∴ $\boxed{W_{net} = W_{paddle} + W_{displacement}}$ → $2000 = -52768T + 6174.2$

Power, $P = \frac{2\pi NT}{60} = \frac{2\pi \times 840 \times 0.08}{60} = 7.03$ Watts. ∴ $T = 0.08$ Joules.

PROB A spherical balloon contains 5 Kgs of air at 200 KPa and 500K. The balloon material is such that pressure inside is always proportional to the square of the diameter. Determine the workdone when the volume of the balloon doubles as a result of heat transfer.

SOL mass, m = 5 Kg, initial pressure, $p_1 = 200$ KPa ; initial temp $T_1 = 500$ K ; Final volume, $V_2 = 2V_1$.

Consider the diameter of the balloon as D, then according to given condition, $p = KD^2$, where K = constant of proportionality

from the perfect gas relation, $p_1V_1 = mRT_1$; $V_1 = \frac{mRT_1}{p_1} = \frac{5 \times 0.287 \times 500}{200} = 3.5875\ m^3$.

we know that volume of the balloon, $V_1 = \frac{4}{3}\pi r^3 = \frac{1}{6}\pi D^3$; $3.5875 = \frac{1}{6}\pi D_1^3$; $\boxed{D_1 = 1.899\ m}$

∴ $V_2 = 2V_1 = 2 \times 3.5875 = 7.175$; $V_2 = \frac{1}{6}\pi D_2^3$; $7.175 = \frac{1}{6}\pi D_2^3$; $\boxed{D_2 = 2.393\ m}$

similarly from the relation; $p = KD^2 \Rightarrow p_1 = KD_1^2$; $K = \frac{p_1}{D_1^2} = \frac{200}{(1.8993)^2} = 55.44$.

workdone by the system, $W = \int_1^2 pdV = \int_1^2 KD^2 dV = K\int_1^2 D^2 d(\frac{1}{6}\pi D^3)$

$= \frac{K}{6} \times \pi \int_1^2 D^2 \times 3D^2 dD = \frac{1}{2}\pi \times 55.44 \int_1^2 D^4 dD = 87.08\left[\frac{D_2^5}{5} - \frac{D_1^5}{5}\right]$

$= 87.08\left[\frac{(2.393)^5}{5} - \frac{(1.8993)^5}{5}\right] = 936.22$ KJ.

Unit 1

1.(a) What are the differences between system and control volume. Explain different types of systems with examples.

(b) A gas undergoes a reversible non-flow process according to the relation P = (-15V+17) where V.is the volume in m^3 and P is the pressure in bar. Determine the work done when the volume changes from 2.8 to 5.6 m^3.

sol: (a)

SYSTEM	CONTROL VOLUME
i) system is defined as definite region (or) area (or) space where thermodynamic process takes place	(i) Control volume is defined as an open system in which mass and energy flows into and out of system.
2) system is focussed to study its properties	(2) control volume is keeping interest for flow energies and matter.
3) system has boundaries and boundary may be fixed (or) movable. Ex:- A Gas enclosed in cylinder bounded by piston with weight on the piston. The piston moves upwards due to heat addition	(3) Control volume is fixed. An open system called Control volume. Ex:- Air compressor, turbines, engines etc. where mass and energy both takes place crosses boundaries.
④ System classified to open, closed, isolated system.	④ control volume is open system. It is one of thermodynamic system

Thermodynamic systems → classification with examples. See First question.

sol: (b)

$p = (-15V+17) \quad V_1 = 2.8\ m^3 ; V_2 = 5.6\ m^3.$

For reversible non-flow process, $W = \int p\,dV = \int_1^2 (-15V+17)\,dV = -15\int_1^2 V\,dV + 17\int_1^2 dV$

$$= -15\left[\frac{V^2}{2}\right]_{V_1}^{V_2} + 17\,[V]_{V_1}^{V_2}$$

$$= -15\left[\frac{V^2}{2}\right]_{2.8}^{5.6} + 17\,[V]_{2.8}^{5.6}$$

$$= -176.4 + 47.6$$

$$= (-128.8)\times 10^5 = -128.8 \times \frac{10^5}{10^3} = -12880\ kJ$$

−ve sign due to work done on the system.

1.(a) Differentiate between Macroscopic Microscopic view points from thermodynamics.

(b) A gas expands according to the equation PV =98, where P is the pressure in kPa and V is the specific volume in m^3/kg. The initial pressure of the gas is 993 kPa and the final pressure is 488 kPa. The gas is then heated at constant volume back to its original pressure of 993 kPa. Determine the work of the combined process. Also sketch the process on P-V and T-S coordinates.

Sol: ①a:

MACROSCOPIC APPROACH (CLASSICAL APPROACH)	MICROSCOPIC APPROACH (STASTICAL APPROACH)
(i) A Certain Quantity of matter is considered without taking into account, the events occuring at molecular level. It called overall behaviour classical thermodynamics	① system considers made up of large no. of molecules. These molecules have different velocities and energies constantly changes with time. So, This approach deals structure of matter. statistical thermodynamics.
② Requires simple mathematical formulae for Analysis.	② Requires Advanced statistical mathematical formulae.
③ properties are Their average values ex:- pressure of gas is average of pressure exerted by millions of Individual molecules. Measured easily by instruments.	③ properties like velocity, momentum, impulse can not be easily measured by instruments
④ In order to describe a system, only few properties are required	④ Large no. of variables needed to describe a system. So, This approach is Complicated.

sol (b)

Isothermal process, $pV^1 = 98$

$p_1 = 993\ kPa$, $p_2 = 488\ kPa$

$p_3 = p_1 = 993\ kPa.$

$PV = 98 = P_1V_1$

Workdone during isothermal process (1-2)

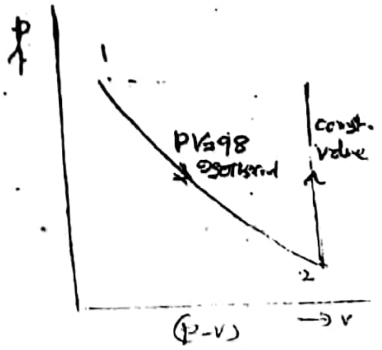
$$W_{1-2} = P_1V_1 \ln\frac{V_2}{V_1} = P_1V_1 \ln\frac{P_1}{P_2} = 98 \ln\frac{993}{488}$$

$= 69.62$ Joules.

Workdone during constant volume process (2-3)

$W_{2-3} = \int p\,dV = 0 \quad [\because \text{since } dV = 0]$

$\therefore$ Total work, $W = W_{1-2} + W_{2-3} = 69.62$ Joules ✓



(P-V)

process 1-2 → isothermal process

2-3 → constant volume process

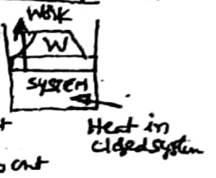
1. (a) What are different types of thermodynamic systems ? Explain them with suitable examples.

(b) A fluid contained in a horizontal cylinder fitted with a frictionless leak-proof piston, is continuously agitated by means of a stirrer passing through cylinder cover. The cylinder diameter is 0.4 during the stirring process lasting 10 minutes, the piston moves out a distance of 0.485 m against a atmosphere. The net work done by the fluid during the process is 2 Kj. The speed of the electric motor driving the stirrer is 840 rpm. Determine torque in the shaft and power output of the motor.

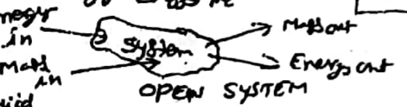
sol: (a) A Thermodynamic system is defined as a certain quantity of matter (or) a prescribed region in space considered for thermodynamic study (or) we focus our attention to study its properties. The study involves changes in properties due to exchange of energy in the form of heat and work. The system may be a quantity of steam, a mixture of vapour and gas etc.

(i) Closed system:- In closed system, the mass is fixed. There is no mass transfer across its boundaries, but energy transfer takes place into (or) out of system in form of heat and work.

Ex:- (A) Heating the gas in a cylinder (B) Hot coffee In a steel tumbler (C) Steam power plant (D) closed cycle gas turbine powerplant.

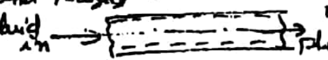


(ii) OPEN SYSTEM:- In open system both mass and energy crosses the boundaries.

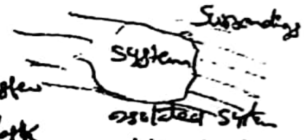


Ex: ① Flow Through tubes and Nozzles.

② water tube boiler



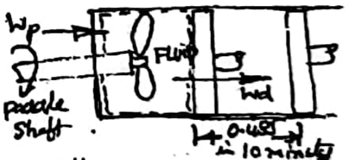
(iii) Isolated system:- In isolated system, there is neither energy transfer nor mass transfer across boundaries. (i) Thermoflask (ii) Insulated chamber.



sol: (b) $W_{net} = W_{displacement} - W_{paddle} = 2000\ J.$

$W_{paddle} = \frac{2\pi NT}{60} = \frac{2\pi\times(840\times10)T}{60} = 879.48T$ — ①

$W_{displacement} = p_{atm}AL = (1.01325\times10^5)\times\frac{\pi}{4}(0.4)^2\times(0.485) = 6174.2$ — ②



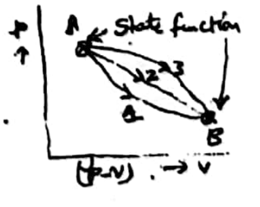
$\therefore W_d - W_p = 2000$; $6174.2 - 879.48\,T = 2000$; $T = 4.746\ Nm$

$\therefore$ Power of paddleshaft, $P = \frac{2\pi NT}{60000} = \frac{2\pi\times8400\times4.746}{60000} = 4.174$ K Watts.

1. (a) What do you understand by a state function and path function

(b) If a gas of volume 6000cm³ and at a pressure of 100 kPa ,is compressed quasistatically to PV^2=Constant until the volume becomes 2000 cm³.Calculate the final pressure the work transfer.

(a) State function:- (or) point function:- The function which depends only on the end states and not on the path followed during a thermodynamic process is known as state function. Ex:- properties of system, i.e, pressure, volume, temp, enthalpy, entropy, internal energy.



Change of state function ; dp, dv, dh, du etc.

path function:- The function which depends on the path of system passed and not on end states known as path function.

Ex:- Heat transfer and work transfer.

The area under each path on (p-v) diagram represents work required for each path, so work is path function. Similarly, Heat also changes according the process which is followed. Heat and work are represented by δQ (or) δW.

sol: (b) Given, $V_1 = 6000\ cm^3$; $p_1 = 100\ KPa$; $V_2 = 2000\ cm^3$.

we know $pV^n = C$; so $p_1V_1^2 = p_2V_2^2$

(i) Final pressure (p_2) ⇒ $p_2 = p_1\left(\frac{V_1}{V_2}\right)^2 = 100\left[\frac{6000}{2000}\right]^2 = 900\ KPa$

(ii) Work transfer (W_{1-2}) $= \frac{p_1V_1 - p_2V_2}{n-1} = \frac{(100\times6000\times10^{-6} - 900\times2000\times10^{-6})\times10^3}{2-1}$

$= -1200$ Joules

$= -1.2$ KJ [-ve sign, work is done on gas]