

19MET201	ENGINEERING THERMODYNAMICS (Use of approved Steam tables is permitted) (Common to Mech, Agri & FT)	L	T	P	J	C
		3	0	0	0	3

UNIT I BASIC CONCEPTS AND FIRST LAW **9**

Basic concepts - concept of continuum - comparison of microscopic and macroscopic approach - Path and point functions - Intensive and extensive - total and specific quantities - System and their types - Thermodynamic Equilibrium State - path and process - Quasi - static - reversible and irreversible processes - Heat and work transfer - definition and comparison - sign convention - Displacement work and other modes of work - P - V diagram - Zeroth law of thermodynamics - First law of thermodynamics - application to closed and open systems - steady flow processes and its applications.

UNIT II PROPERTIES OF PURE SUBSTANCE **9**

Formation of steam and its thermodynamic properties - P-V, P-T, T-V, T-s, h-s diagrams. P -V-T surface - Use of Steam Table and Mollier Chart - Determination of dryness fraction using Throttling, Separating and Throttling - Application of I law for pure substances.

UNIT III SECOND LAW **9**

Second law of Thermodynamics - Statements of second law and its corollaries - Carnot cycle - Reversed Carnot cycle - Performance - Carnot theorem - Clausius equality - inequality.

Qualitative Treatment only: Concept of Entropy -T-s diagram -entropy change for pure substance - ideal gases - different processes - principle of increase in entropy - Applications of II Law - exergy analysis and its applications

UNIT IV STEAM POWER CYCLES **9**

Ideal and actual Rankine cycles - Cycle Improvement Methods - Reheat and Regenerative cycles, **Qualitative Treatment only:** Economiser- Preheater - Superheater- Condenser- Cogeneration Introduction - Binary and Combined cycles.

UNIT V IDEAL AND REAL GASES, GAS MIXTURE, THERMODYNAMIC RELATIONS **9**

Mole and Mass fraction - Dalton's. Properties of gas mixture -Molar mass - gas constant - density. Properties of Ideal gas - Ideal and real gas comparison - Equations of state for ideal and real Gases - Reduced Properties - Compressibility Factor - Maxwell relations - Tds Equations - Difference and ratio of heat Capacities - Energy Equation -Joule -Thomson Coefficient - Clausius - Clapeyron equation and its applications.

L : 45 T: 0 P: 0 J: 0 TOTAL: 45 PERIODS

TEXT BOOKS

1. Nag.P.K., "Engineering Thermodynamics", 5th Edition, Tata McGraw - Hill, New Delhi, 2013.
2. Cengel. Y and M.Boles, "Thermodynamics - An Engineering Approach", 8th Edition, Tata McGrawHill 2014.

REFERENCES

- 1 Moran, Shapiro, Boettner & Bailey "Principles of Engineering Thermodynamics:" Wiley & Sons, 2015.
- 2 Holman.J.P. "Thermodynamics", 3rd Edition, McGraw - Hill, 1995.
- 3 Rathakrishnan. E., "Fundamentals of Engineering Thermodynamics", 2nd Edition, Prentice - Hall of India Pvt. Ltd, 2006
- 4 Arora C.P, "Thermodynamics", Tata McGraw - Hill, New Delhi, 2007.
- 5 Kau - Fui Vincent Wong, "Thermodynamics for Engineers", CRC Press, 2010 Indian Reprint.

COURSE OUTCOMES

At the end of the course student should be able to:

- CO1** Describe the laws of thermodynamics and their application to a open and closed of systems.
- CO2** Determine dryness fraction of pure substances undergoing processes using Mollier entropy in real time applications.
- CO3** Demonstrate Carnot, Clausius equality and Inequality theorems and apply the principles of entropy in real time applications
- CO4** Illustrate the principles of various steam power cycles and to solve problems related to steam undergoing various processes

19MET201 Engineering Thermodynamics

L T P J C
3 0 0 0 3

Dr. V. Karthi
AP/MECH SNSCT

UNIT - 1

BASIC CONCEPTS OF FIRT LAW

INTRODUCTION

UNIT-1 BASIC CONCEPTS AND FIRST LAW

Thermodynamics

The branch of science, which deals with the relation between heat, work and properties of system, is called

Thermodynamics.

Important terminology and units and Properties:

Density:

Density is defined as the mass per unit volume. It is denoted by ρ (rho) in S.I units.

$$\text{Density } \rho = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Kg}}{\text{m}^3}$$

It is also denoted by specific mass or mass density.

Specific Volume:

Volume occupied by unit mass of the substance. It is reciprocal of density.

$$\text{Specific Volume } v = \frac{\text{Total Volume}}{\text{Mass}} = \frac{V}{m}$$

S.I unit expressed as m^3/kg

Specific Weight:

• Weight for unit Volume S.I unit it is

Expressed as ~~m²/kg~~ N/m^3 or kN/m^3

$$\text{Specific Volume } v = \frac{\text{Total Weight } W}{\text{Total Volume } V}$$

Specific Gravity:

Specific Gravity = $\frac{\text{Specific Weight of the given substance}}{\text{Specific Weight of the standard substance}}$

Pressure:

$$\text{Pressure } p = \frac{\text{Force } F}{\text{Area } A}$$

Pressure: A Normal force exerted by a fluid per unit Area
 $1 \text{ Pa} = 1 \text{ N/m}^2$

1 pascal = 1 N/m^2

1 Bar = $1 \times 10^5 \text{ N/m}^2 = 100 \text{ kN/m}^2$

1 bar = $10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$

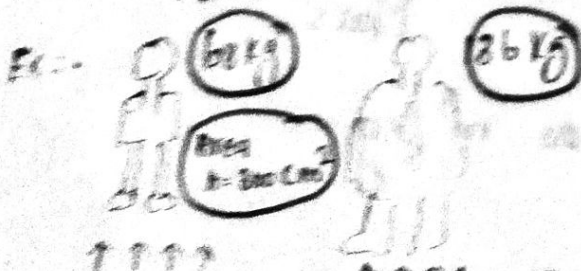
1 Torr = 1 mm of Mercury (Hg) = 133.3 N/m^2

1 mm of Water (H_2O) = 9.80665 N/m^2

1 bar = 100 kPa

1 atm = $1.01325 \text{ bar} = 101.325 \text{ kPa}$

1 atm = 760 mm of Hg = 1033.176 mm of Water



The normal stress (or pressure) on the fat of a chubby person is much greater than on the fat of a slim person

$p = \frac{68}{300} = 0.227 \text{ kgf/cm}^2$

$p_2 = \frac{26}{300}$

0.453 kgf/cm^2

Energy:

1-2

SI unit of energy = Joule

$$1 \text{ Joule} = 1 \text{ Nm}$$

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{\text{Energy Store or transfer}}{\text{time taken}}$$

The unit of Power in S.I is Watt [W]

$$1 \text{ W} = 1 \text{ N}\cdot\text{m/s} = 1 \text{ J/s}$$

Specific heat Capacity (c)

The Quantity of heat transfer, required for raising or lowering the temperature of unit mass of the substance through one degree. It is denoted by c and is expressed is J/kgK or KJ/kgK

Specific heat Capacity at Constant Volume [C_v]

The Quantity of heat transfer, required for raising or lowering the temp of unit mass of substance through one degree when the volume remain constant.

$$\text{Heat transfer } Q = m C_v [T_2 - T_1]$$

Q: Heat transfer

C: Constant Volume

T₁ T₂: Temp

Specific heat capacity of Constant Pressure $[C_p]$

The quantity of heat transfer required to raise or lower the temperature of unit mass of the substance through one degree when the pressure is kept as constant

when the gas is heated or cooled at constant pressure

$$\text{Heat transfer } Q = m c_p [T_2 - T_1]$$

Q = Heat transfer

c_p = Constant Pressure

T_1, T_2 = Temperature.

Note :-

Solid and liquids have only one specific heat capacity.

Gases and vapours have two specific heat capacities.

C_p and C_v are properties of a substance not

constant. They vary with pressure and temperature.

The Quantity of heat transfer, required for raising or lowering the temperature of unit mass of the substance through one degree". It is denoted by C and is expressed as J/kgK or KJ/kg K

Specific heat capacity at Constant Volume [C_v]

The Quantity of heat transfer, required for raising or lowering the temp of unit mass of substance through one degree when the volume remain constant.

$$\text{Heat transfer } Q = m C_v [T_2 - T_1]$$

Q: Heat transfer

C: Constant Volume

T₁ T₂: Temp

Microscopic and Macroscopic Approaches:

2 different Approach of Thermodynamics Studies:

Thermodynamically, the behaviour of any matter can be studied in two different Point View.

1. Microscopic approach (or) Statistical thermodynamics

2. Macroscopic approach (or) Classical thermodynamics

(i) A substance or matter consist of a large no. of particles called molecules.

Properties of substance naturally depend on the behaviour of these molecules.

Macro mean big or total

Microscopic mean small

Macroscopic approach :-

• Certain Quantity of Matter or Substance considered with out taking into account the events occurring Molecular level.

• In other words this approach to thermodynamics is concerned with gross or overall behaviour. Th

The behaviour of total system in terms of properties of
Such as Pressure, Volume, temperature etc... are
Studied.

• The ~~above~~ above properties can easily
Measured.

- This is also called as macroscopic approach.
It is known as classical thermodynamics.

Example:

I. C Engine

• The system contain mixture of air & petrol vapour
in the cylinder of I. C Engine.

The properties as

• Pressure

• Temp

• Volume

measured for

each position in the cylinder.

• The mixture of air and petrol vapour

can be determined by means of above mentioned
properties. These are called macroscopic properties.

• The macroscopic energy of system is

related to motion and influence of some of
external effect like

Surface tension,

gravity

magnetism

electricity

Microscopic approaches:

Microscopic approaches:

- The microscopic approach considers individual molecules of the system only. [discrete the substance]
- In this approach the properties of matter such as Velocity, Impulse, Momentum, Kinetic energy Position, ~~of the~~ of the individual molecule at a given instant or at a particular time are studied.
- This is known as statistical thermodynamics.

Homogeneous and heterogeneous system

- A quantity of matter homogeneous throughout in Chemical composition and physical structure is called phase.
- Every substance can exist in any one of three phases via solid, gas & liquid.
- A system consisting of a single phase is called homogeneous system.
- A system consisting of two more phase is called heterogeneous system.

Thermodynamic system:

It is classified into three types

1. Closed system (or) Control Mass
2. Open system (or) Control Volume
3. Isolated system

Thermodynamic system is defined as a Quantity of Matter (or) fixed mass and Identity which is bounded by a closed Surface.

Ex:

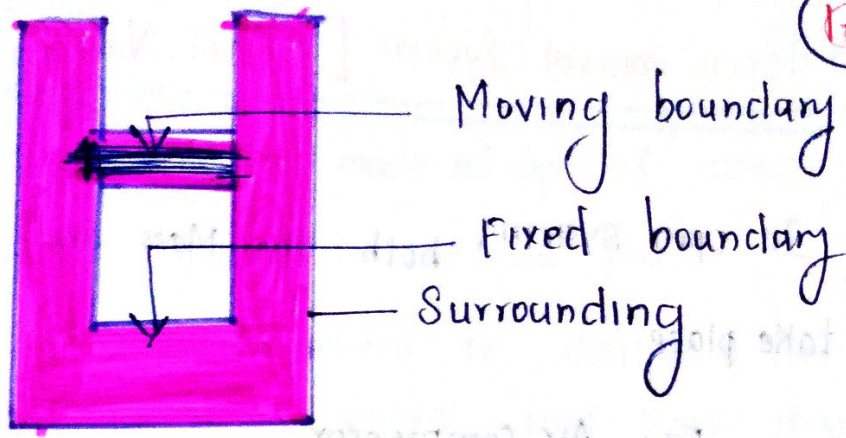
A Vessel containing liquid forms a thermodynamic system with wall of the vessel forming real boundary surface.

Surrounding:-

Anything outside the system which affects the behaviour of the system is known as Surroundings or environment. (or) Outside the system is called Surrounding.

Boundary :-

Boundary is an imaginary surface which separates the system from its surrounding.



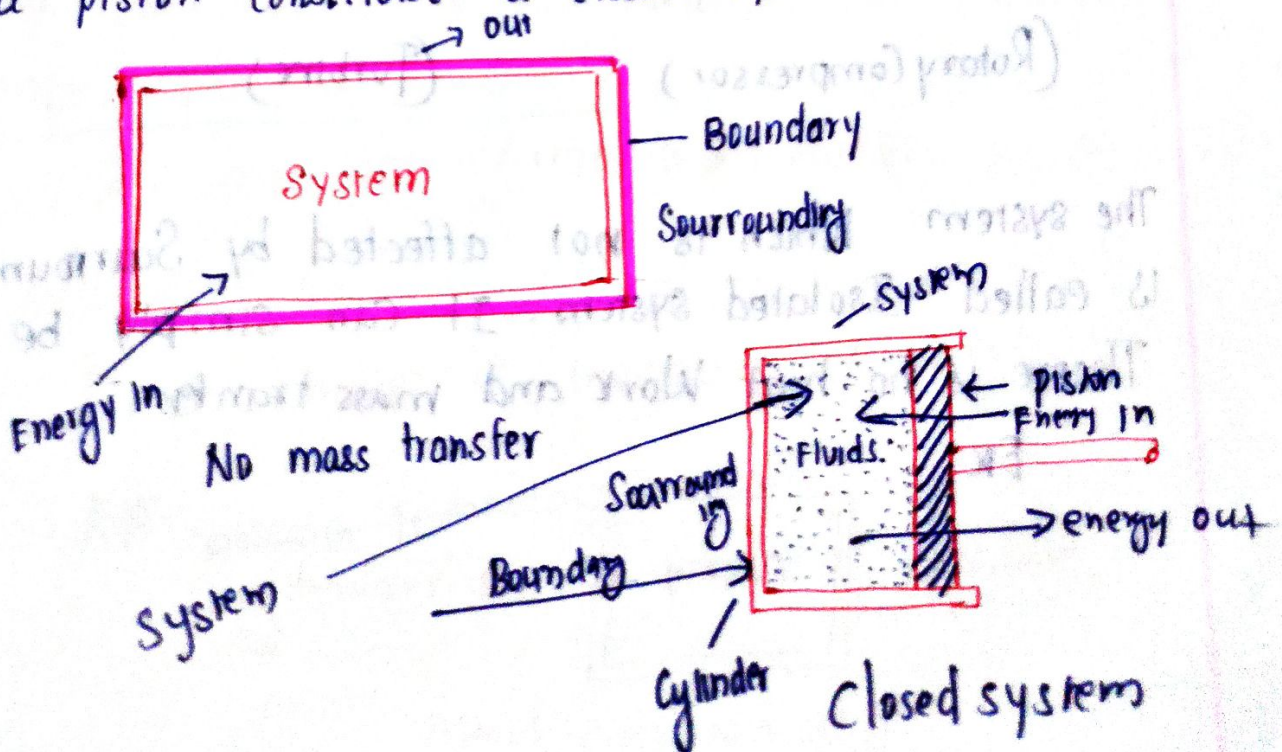
(i) Closed system or Control Mass

• A closed system does not allow or permit any mass transfer. But only the energy transfer takes place.

• There is no mass transfer across the boundary.

Ex:-

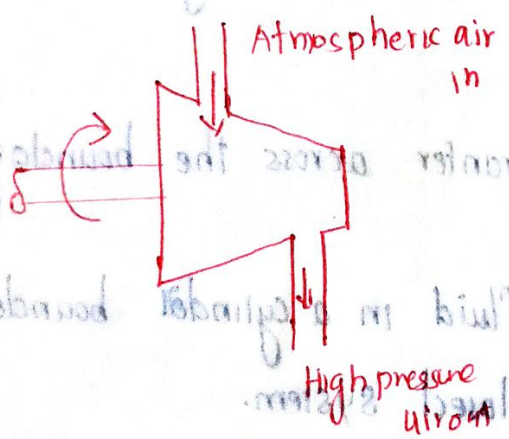
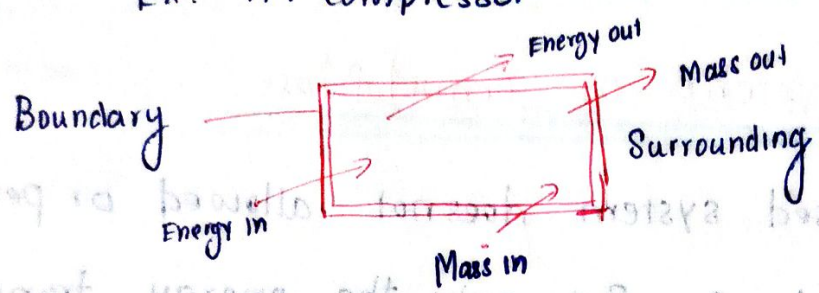
Certain amount of fluid in a cylinder bounded by a piston constitutes a closed system.



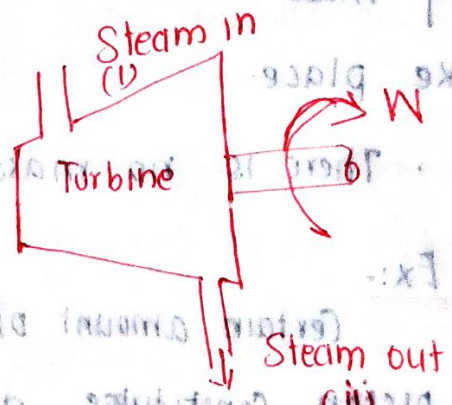
Open ~~control~~ system [Control Volume]

In open system, both the Mass and Energy transfer take place.

Ex: Air Compressor



(Rotary Compressor)

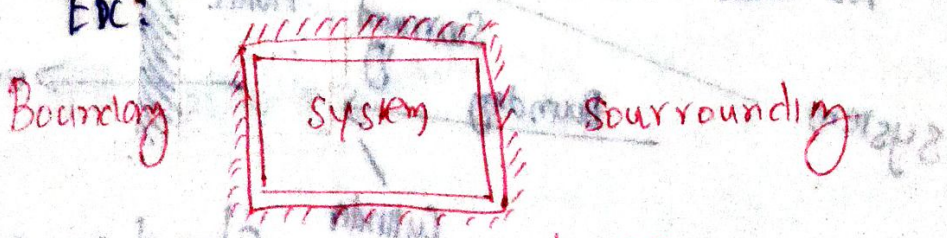


(Turbine)

Isolated system:

The system which is not affected by Surrounding is called Isolated system. It can simply be stated. There is no heat Work and mass transfer.

Ex:

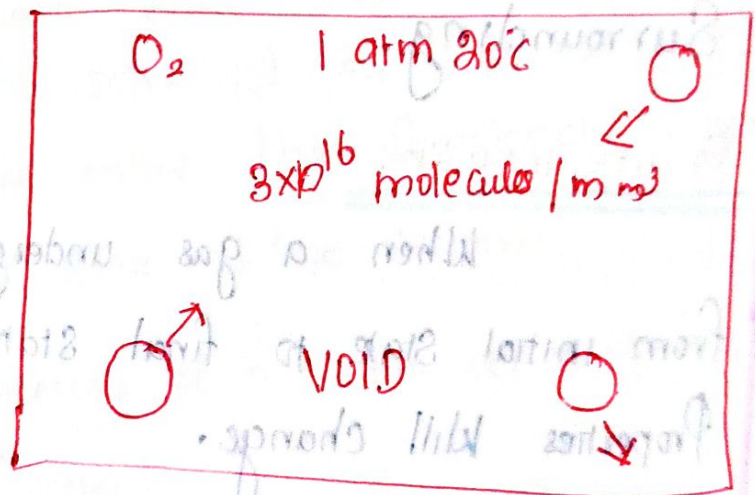


No mass energy transfer.

Continuum:

• matters or substance made up of atoms that are widely spaced in the gas phase.

• It is very convenient to disregard the atomic nature of a substance and view it as a continuous homogeneous matter with no holes that is a continuum.



The matter or substance is instead in this case as continuous and in this the behaviour of individual molecule is not studied

We are interested in average behaviour of molecule.

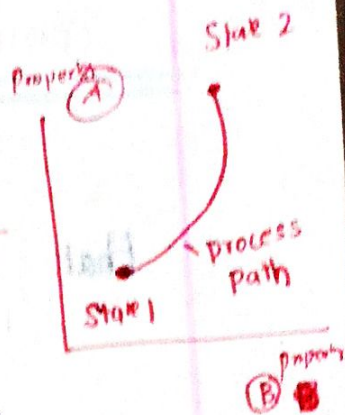
It is similar to macroscopic approach

~~missile technology~~

Path function and Point function:

Path:

• A series of state through which system passes during a process.



To describe a process completely one should specify initial and final states as well as the path it follows, and the interactions with the surrounding.

Point function:

When a gas undergoes a process from initial state to final state, the thermodynamic properties will change.

Some of the properties such as pressure, volume and temperature are not depending upon the path followed by a system. It is purely independent of the path followed by a process. These properties called as Point function or State function.

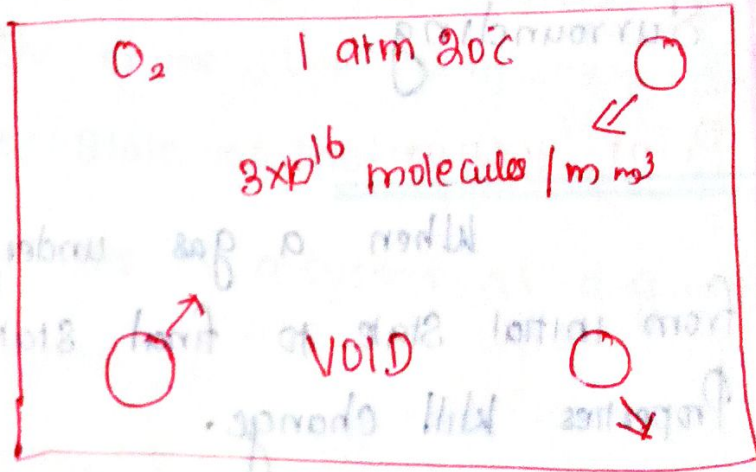
Ex: Pressure
Volume
Temp etc..

Continuum:

• matter or substance made up of atoms that are widely spaced in the gas phase.

• It is very convenient to disregard the atomic nature of a substance and view it as a

Continuous: The homogeneous matter with no holes that is a Continuum.

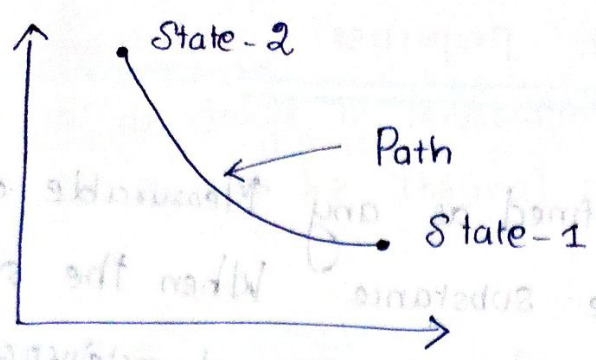


The matter or substance is instead in this case as continuous and in this the behaviour of individual molecule is not studied

molecule. We are interested in average behaviour of molecule.

It is similar to macroscopic Approach

~~APP~~ missile technology



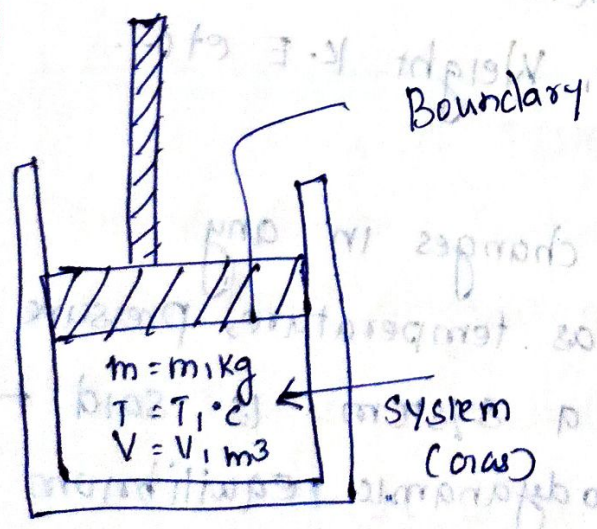
State-1 state - 2. Process

Process and Path

State:

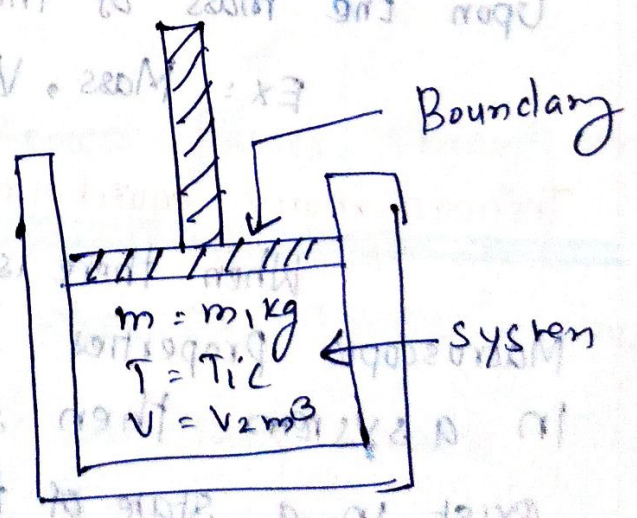
A system considered which does not undergo any change. At this point all the properties can be measured throughout the entire that completely describes the condition or the state of the system.

All the properties of a system at a given state have fixed values.



State 1

(compressed state of gas)



State 2

State - Expanded State of

gas

Law of thermodynamics:

Intensive and Extensive Properties:

Properties :-

It is defined as any Measurable or observable Characteristics of the substance when the system remains in equilibrium state. any characteristics of a System is called Property.

Ex: Pressure, temperature, Volume, mass

Intensive Properties:-

Intensive properties are Independent of the mass of the system.

Ex: Pressure, temperature, Specific Volume, etc..

Extensive Properties:

Extensive properties are dependent upon the mass of the system.

Ex: Mass, Volume, Weight, K.E etc...

Thermodynamic equilibrium:

When there is no changes in any Macroscopic Properties such as temperature, pressure etc. In a system then such a system is said to exist in a state of thermodynamic equilibrium.

1. Thermal equilibrium
2. Mechanical equilibrium
3. Chemical equilibrium

Zeroth law of thermodynamics:

1-8

Thermal equilibrium:

If there is no change in temperature with time in a system. It is said to be thermal equilibrium.

Mechanical equilibrium

If there is no change in pressure of force with time, that system is mechanical equilibrium.

Chemical equilibrium

Any system is said to be in chemical equilibrium if all possible chemical reactions in the system have taken place and there is no change of phase with time.

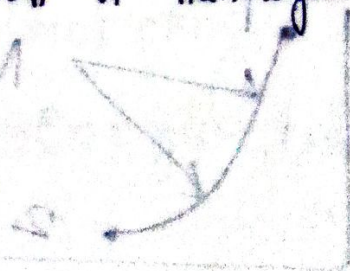
A system is said to be in chemical equilibrium when there is no chemical reaction throughout the system.

Quasi Static Process:

A system process passes through an infinite no. of continuous equilibrium states and attains the original state when the process is reversed.

This process is called as quasi static process.

• It is succession of thermodynamic equilibrium.



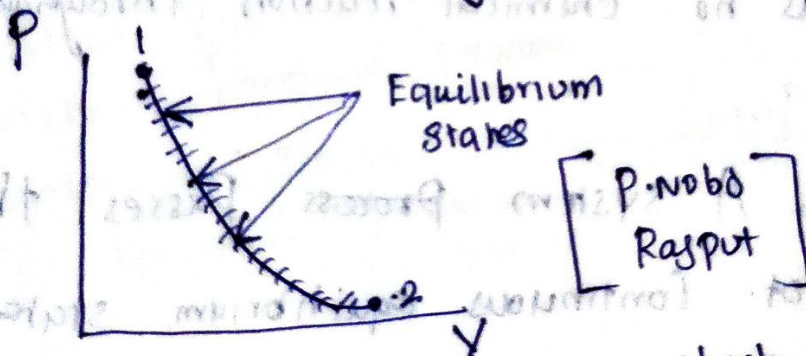
Reversible and Irreversible Processes

A system passes through an infinite no. of continuous equilibrium states and it traces same path when this process is reversed. This process is known as reversible process.

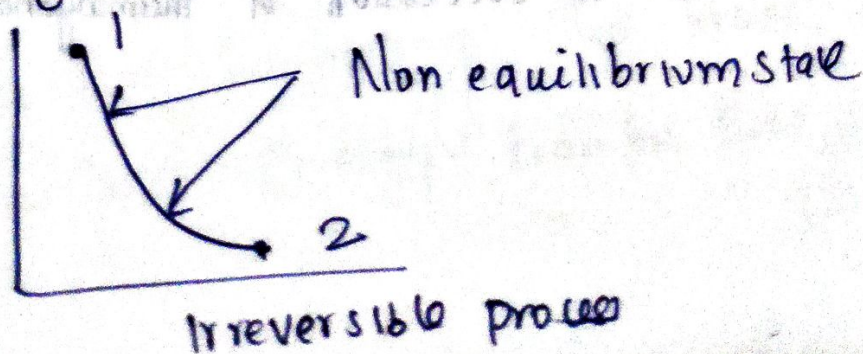
Ex: Constant Volume, Constant Pressure, Isothermal, adiabatic processes etc..

A system passes through an ~~no.~~ infinite no. of continuous non-equilibrium states and does not trace same path when the process is reversed. This process is known as irreversible process.

Ex: free expansions, throttling, and steady flow analysis



A reversible process is one which can be stopped any stage and reversed so that the system and surrounding are exactly restored to their initial states.



Flow and Non flow process

A flow process the working fluid enters the system level and leaves it to atmosphere after doing at work

In this system energy and Mass cross the Boundary.

Ex: steady flow process applied to Various systems Such as boilers, turbines, Compressor etc.

In non flow process the same working fluid is recirculated again and again. It doesnot leave the system after doing the work.

- Ex: Constant Volume process
- Constant Pressure process
- Isentropic process
- Iso thermal process

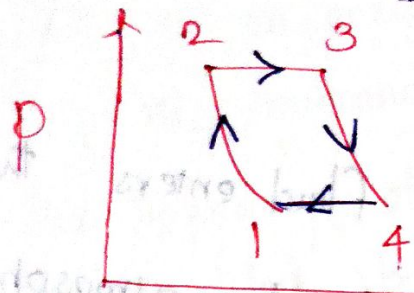
Thermodynamic Cycle:

Open Cycle:

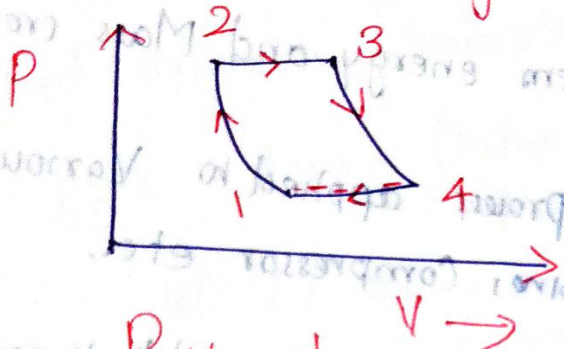
The working substance is exhausted to atmosphere after completing the process. So here both mass and energy transfers take place.

Transfer and sign Conversion:

interaction between



P-V diagram of a closed cycle



P-V diagram of closed cycle.

Concept of temperature and Thermal equilibrium:

Heat transfer:-

Heat is defined as the energy crossing the boundary of a system due to temperature difference between system and surrounding.

It is usually represented by Q and expressed in Joule or kJ

$$Q = m \cdot C \cdot [T_2 - T_1] = m C dT$$

The unit of heat transfer is J or kJ

Where C Specific heat of substance.

Work transfer and sign Conversion:

1-10

• Work is an energy interaction between a system and its surrounding. Usually the energy can cross the boundary of any system in the form of either heat or work. But

• But the energy crossed through the boundary in a closed system is definitely in the form of work.

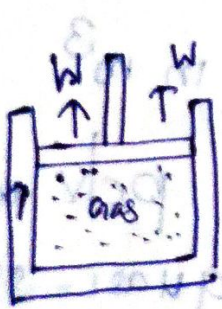
Work = Force \times Distance Moved

$$W = F \times x$$

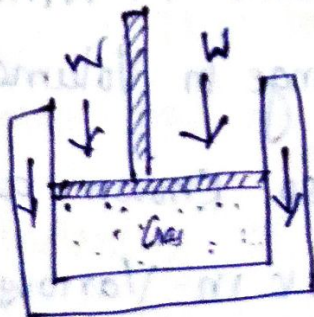
The work expressed in terms of N-m or J

The work done per unit time is called Power

Unit Power is kJ/s or kW



①

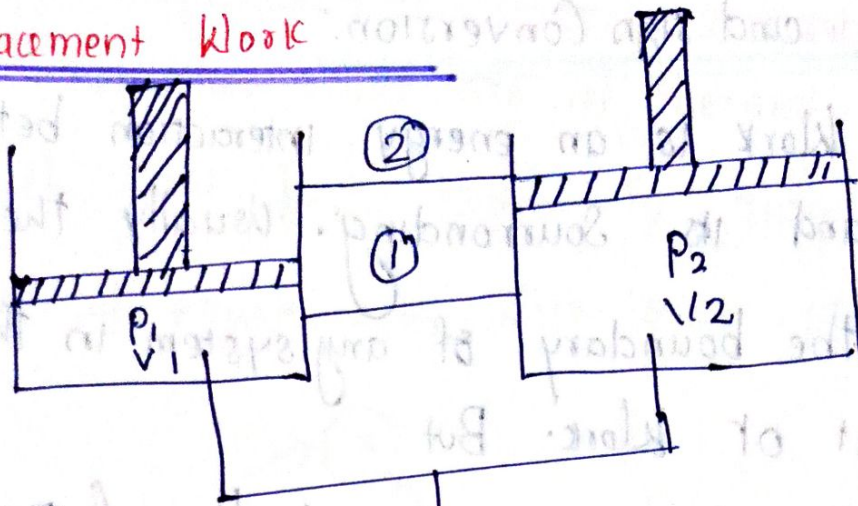


②

(1) Work done by the system. Gas expands and pushes the piston upwards. Work is positive.

(2) Work done on the system. Gas is compressed by pushing the piston downward. Work is negative.

Displacement Work



Gas system

When piston moves out from position ① to position ② as shown with volume changing from V_1 to V_2 the amount of work done W by the system

will be

$$W_{1-2} = \int_{V_1}^{V_2} p \, dV$$

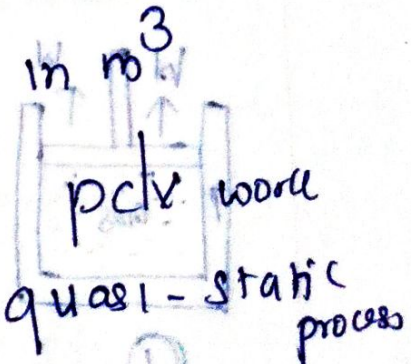
$$W_{1-2} = \text{work done in Nm}$$

p = Pressure in N/m^2

dV = change in volume in m^3

Displacement work is also known as

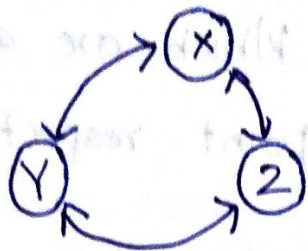
$p \, dV$ = work in various quasi-static process



Zeroth law of thermodynamics:

1-11

When two bodies are in thermal equilibrium with 3rd body separately, they are also in thermal equilibrium with each other.



Concept of temperature and thermal equilibrium:

Temperature:

- Temperature is ~~measure the~~ the measure of Molecular Velocity of fluid Particles.
- It is ~~the~~ ^a property which is used to determine the degree of hotness or coldness or level of heat intensity of body.
- The level of temperature is expressed

Qualitatively in words such as freezing cold, warm, hot and red hot

Thermal equilibrium:-

A system said to be in thermal equilibrium when there is no temperature difference throughout the system.

Temperature scale :-

- It is provide a Common basis for temperature Measurement.
- All temperature scale are based on easily reproducible state such as the freezing and boiling points of water which are also called ice point and steam point respectively.
- A mixture of ice and water in equilibrium with air saturated with vapour at 1 atm pressure is said to be at the ice point.
- A mixture of liquid water and water vapour in equilibrium at 1 atm pressure is said to be at the steam point.

Relationship b/w temp scale :-

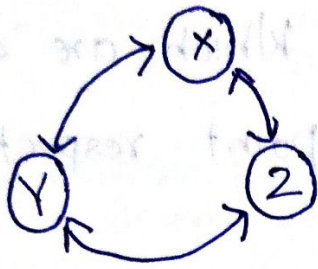
The relation b/w Celsius and Fahrenheit scale is represented by the following equation

$$^{\circ}\text{F} = 32.0 + (9/5) ^{\circ}\text{C}$$

$$^{\circ}\text{C} = (F - 32.0) (5/9)$$

zeroth law of thermodynamics:

When two bodies are in thermal equilibrium with 3rd body separately, they are also in thermal equilibrium with each other.



Concept of temperature and thermal equilibrium:

Temperature:

- Temperature is ~~measure the~~ measure of Molecular Velocity of fluid Particles.
- It is ~~the~~ ^a property which is used to determine the degree of hotness or coldness or level of heat intensity of body.

• The level of temperature is expressed Quantatively in kelvins such as freezing cold, warm, hot and red hot

Thermal equilibrium:-

A system said to be in thermal equilibrium when there is no temperature difference throughout the system.

Fundamental units:

physical Quantity is one of Most important Operations in engineering

Every Quantity is measured in terms of some arbitrary but Internationally accepted unit, called Fundamental units

Ex: meter, Kilogram, second, ampere, Kelvin, mole etc.

SI units (International standard units)

Derived units:

Derived units are units which may be expressed in terms of base units by means of mathematical symbols of multiplication and division.

Ex: area, Volume, Speed, Velocity etc..

F.P.S units:

In this system the fundamental units of length mass and time are Foot, Pound and Second respectively

M.K.S units:

In this system the fundamental units of length mass and time are Mass, Kilogram and Second respectively

Derived units:

linear Velocity	V	m/s
acceleration	a	m ² /s ²
Angular Velocity	ω	rad/s
acceleration	α	rad ² /s ²
mass density	ρ	kg/m ³
Force weight	F, W	N: IN = kgm/s ²
Gas constant	R	J/kg K
Thermal Conductance	h	W/m ² K

Quasi-static Process

(62) ... me of the reversible ... Δ ... it piston m atmosphere away

Metre:

The metre is defined as the length equal to 1650763.73 wave length in Vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the Krypton-86 atom

Kilogram:

~~Kilogram~~ is base unit of mass in the international system

Kilogram is the base unit of Mass in the International system of Units (SI) and is defined as being equal to the mass of the International Prototype of the Kilogram.

Second:

Second is defined as duration of $9,192,631,770$ Period of the radiation corresponding to the transition between the two hyperfine level of the ground state of the Caesium-133 atom

1980 Robert Williams
(It is symbol of atomic number)

hyper fine mean

- extremely fine or thin
- being related to fine structure multiple occurring in an atomic spectrum due to interaction b/w electron & nuclear spin

Kelvin:

It is defined as fraction $1/273.6$ of the thermodynamic temp of triple point of water

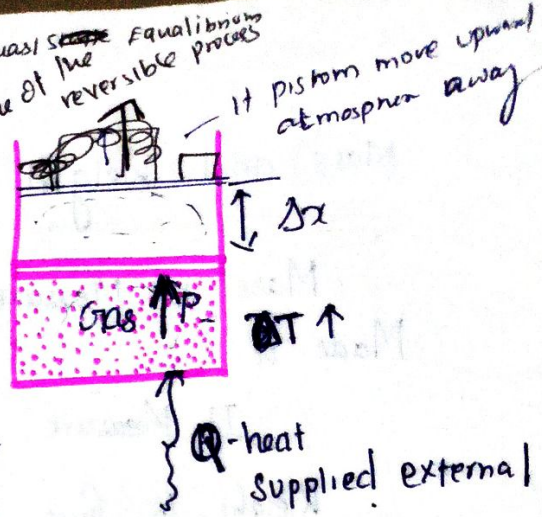
Greek symbols:

- α absorptivity
- ρ ratio of Specific heat
- ϵ emissivity
- η efficiency
- Δ temperature difference

Quasistatic Process

(b) Quasi ~~static~~ Equilibrium process
It is one of the reversible process

The process in which at every instant during the process system is considered to be in equilibrium.



Let us consider a fig with light weight piston.

→ supply heat → Temp Increase ~~automatically~~ pressure

• If temp increase na gas molecule will have more kinetic energy in due to high no. of polygon. so due to piston move up Δx

- Piston is move up create vacuum in
- Gases are diffuse in vacuum phase.

at time we cant define P & T and also we cant apply any Law during the process

The piston move very slowly upward direction

• we cant specify press value

• The gas fill uniform

In nature only very slow process can be approximated as quasistatic is nature.

- we can state all process in nature are non

Equilibrium process

the system very slow reason
Instant gas uniformly fill space

W T 4U

clear 5 minutes video (Piston) high level 3 min, 4 min

Inspection

Youtube Videos

P, V not defined during vacuum area

Mass and Weight



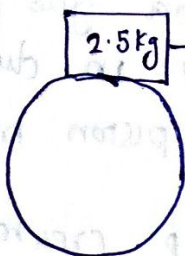
Mass is Measure of Amount of Material an object is Made of.

It Measure by Kg

Weight is force of Gravity on an objects.

It measure by Newtons

Ex:



Earth
 $g = 9.8$



Moon
 $g = 1.6$

P.F: Potential energy:
Energy Passed by any system (or body)
by virtue of height.

P.F: $mg \times 2$
[by virtue of position above the ground level]

2: take ground level

Specific Gravity of Some Substance:

~~Water~~ ~~Sea~~

Substance	Specific Gravity
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3 to 0.9
Gold	19.2
Ice	0.92
Air (at 1 atm)	0.0013

K.E: Kinetic energy:

Energy Passed by any system (or body)
by virtue of its velocity

$KE = \frac{1}{2} mv^2$
Velocity in m/sec

Celsius scale is converted into kelvin

1-12

$$T = t + 273K$$

Where

T - Temp on Kelvin scale

t - Temp on Celsius

Scale

Kelvin scale

100°C	373 K
0°C	273 K
-273°C	0 K

The magnitude of each division of 1 K and 1°C are identical.

$$\Delta T [K] = \Delta T [^{\circ}C]$$

First law of Thermodynamic system

When a system undergoes a cyclic process then the net heat transfer is equal to the net work transfer.

Mathematically

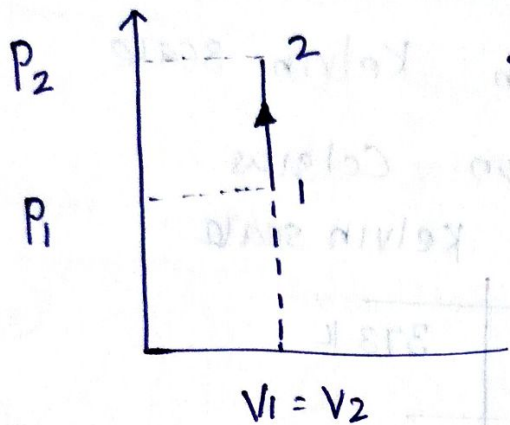
$$\oint Q = \oint \delta W$$

Heat transfer = Work done + Change in internal energy

$$Q = W + \Delta U$$

First law of Thermodynamics - Application to closed system

1. Constant Volume Process



• P_1 & P_2 are Pressure at Initial and Final states

• T_1 & T_2 " tempe at

" "

• V_1 & V_2 are Volume at

" "

P - V diagram

Relation between p V and T

$$\frac{pV}{T} = C$$

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

In this process $V_1 = V_2$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \text{or} \quad \frac{P_1}{P_2} = \frac{T_1}{T_2}$$

Quasi Static Process

1. ALL

1-20

6) The Internal energy of Certain Substance is given by the following equation

$$u = 3.56 PV + 84$$

u is given in kJ/kg P is in kPa and V is in m^3/kg

A system composed of 3kg of Substance expand from Initial Pressure of 500 kPa and Volume of 0.22 m^3 to a final Pressure 100 kPa in Process in which Pressure and Volume related by $PV^{1.2} = \text{constant}$.

(a) if expansion is Quasi static find Q , Δu , W

(b) if another process ^{the} Same system expands according to

the same Pre-Volume in Part (a) from initial state to same final state as in part (a) but heat transfer in this case is 30 kJ Find the Work transfer Process

Diff b/w work transfer Part a & B

Q. D.:

$$u = 3.56 PV + 84$$

$$P_1 = 500\text{ kPa}$$

$$P_2 = 100\text{ kPa}$$

$$V_2 = 0.22\text{ m}^3$$

$$PV^{1.2} = \text{constant}$$

Sol.:

$$u = 3.56 PV + 84$$

$$\Delta u = u_2 - u_1 = 3.56 [P_2 V_2 - P_1 V_1]$$

$$\Delta u = 3.56 [P_2 V_2 - P_1 V_1]$$

$$P_1 V_1^{1.2} = P_2 V_2^{1.2}$$

$$V_2 = V_1 \left[\frac{P_1}{P_2} \right]^{1/1.2}$$

using calculator symbol \wedge

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

$$0.22 \left[\frac{5}{1} \right]^{1/1.2}$$

$$= 0.22 \times 3.83 = 0.845 \text{ m}^3$$

$$\boxed{V_2 = 0.845 \text{ m}^3}$$

$$\Delta U = 356 [P_2 V_2 - P_1 V_1]$$

$$= 356 [1 \times 0.845 - 5 \times 0.22] \text{ KJ}$$

$$\boxed{\Delta U = -91 \text{ KJ}}$$

For Quasi static process

$$W = \int P dy = \frac{P_2 V_2 - P_1 V_1}{n-1}$$

$$= \frac{1 \times 0.84 - 5 \times 0.22}{1-1.2}$$

$$\boxed{W = 127.5 \text{ KJ}}$$

Heat transfer $Q = \Delta U + W$

$$= -91 + 127.5$$

$$\boxed{Q = 36.5 \text{ KJ}}$$

(b) Here $Q = 30 \text{ KJ}$

Since the end state are same, ΔU would remain same in (a)

$$W = Q - \Delta U$$

$$= 30 - (-91)$$

$$\boxed{W = 121 \text{ KJ}}$$

(c) The Work in (b) is not equal to $\int P dy$ since the Process is not Quasi static.

A boiler produce Steam from Water at 35°C. The enthalpy of Steam is 2675 KJ/Kg. Calculate the heat transferred per kg. The sp. heat capacity of water is 4.19 KJ/kg. Neglect the potential and kinetic energies.

Gr. D :

$$T_w = 35^\circ\text{C} = 35 + 273 = 308\text{ K}$$

$$h_2 = 2675\text{ KJ/Kg}$$

$$C_{pw} = 4.19\text{ KJ/Kg K}$$

To find

Heat transferred Q

Sol.:

Enthalpy of feed water

$$h_1 = C_{pw} \times T_w = 4.19 \times 308 = 1290.52\text{ KJ/Kg}$$

SFEE for boiler, heat transferred Q

$$Q = h_2 - h_1$$

$$Q = 2675 - 1290.52$$

$$Q = 1384.48\text{ KJ/Kg}$$

Quasi static

(1-19)

A mass of 1.5 kg of air is compressed in Quasi static Process from 0.1 MPa to 0.7 MPa for which $PV = \text{Constant}$. The initial Density of air is 1.16 kg/m^3 . Find the Workdone by the Piston to Compress the air

G.D.:

$$\text{Mass } P = 1.5 \text{ kg}$$

Process : Quasi Static

$$\text{Density } \rho = 1.16 \text{ kg/m}^3$$

$$\text{Pressure } P_1 = 0.1$$

$$P_2 = 0.7$$

Find: Work done

for Quasi static Process

$$\begin{aligned} \text{Work done} &= \int P dv \\ &= P_1 V_1 \int_{V_1}^{V_2} \frac{dv}{V} \\ &= P_1 V_1 \ln \left[\frac{V_2}{V_1} \right] \\ &= P_1 V_1 \ln \left[\frac{P_1}{P_2} \right] \end{aligned}$$

Density: $\frac{\text{mass}}{\text{Volume}}$

$$V_1 = \frac{1.5}{1.16}$$

$$V_1 = 1.239 \text{ m}^3$$

$$= 0.1 \times 1.239 \ln \left[\frac{0.1}{0.7} \right]$$

$$W = -0.24109 \text{ KJ}$$

Given $PV = \text{Constant}$

$$PV = C$$

$$P_1 V_1 = PV = P_2 V_2 = C$$

$$P = \frac{P_1 V_1}{V}$$

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

Given $P = 0.1 \text{ MPa}$

$$V = \frac{m}{\rho} = \frac{1.5}{1.16} \text{ m}^3$$

2 A mass of gas is compressed in Quasi Static Process from 80 kPa .
 0.1 to 0.4 MPa, 0.03 m³. Assuming that Pressure and Volume
 are related by $PV^n = \text{Constant}$ find the work done by gas
 Q. D

$$P_1 = 80 \text{ kPa}$$

$$V_1 = 0.1 \text{ m}^3$$

$$P_2 = 0.4 \text{ MPa} = 400 \text{ kPa}$$

$$V_2 = 0.03 \text{ m}^3$$

$$W = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

As P-V relation $PV^n = C$

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

taking log e both side

$$\ln P_1 + \ln V_1 = \ln P_2 + \ln V_2$$

(or)

$$n \ln [V_1 - V_2] = \ln P_2 - \ln P_1$$

(or)

$$n \ln \left[\frac{V_1}{V_2} \right] = \ln \left[\frac{P_2}{P_1} \right]$$

$$n = \frac{\ln \left[\frac{P_2}{P_1} \right]}{\ln \left[\frac{V_1}{V_2} \right]}$$

$$\frac{\ln \frac{400}{80}}{\ln \left[\frac{0.1}{0.03} \right]}$$

$$\frac{1.60944}{1.20397}$$

$$n = 1.34$$

$$\text{Work done} = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{80(0.1) - (400 \times 0.03)}{1.34 - 1}$$

$$1.34 - 1$$

$$W = -11.746 \text{ kJ}$$

~~n~~ has any value from zero to infinity which depend upon the process

First law of Thermodynamics Problem

1. During cycle sum of all heat transfers is -200 kJ. The system complete 2 cycles per sec. Complete the following table, showing Method for each item and compute Net rate of work output in kW.

Process	Q in kW	W in kW	ΔE in kW
a-b	0	36	-
b-c	350	0	-
c-d	-35	-	-610
d-a	-	-	-

Solution:

Process a-b = 1st law of Thermodynamics

i.e. $Q = \Delta E + W$

G.D = $Q = 0$
 $W = 36$
 $\Delta E = ? \text{ Nil}$

Process a&b

$Q - W = \Delta E$
 $0 - 36 = ?$
 $\Delta E = 36 \text{ kW}$

Process b-c

$Q = \Delta E + W$

Providing G.D in b-c

$Q = 350$
 $W = 0$
 $\Delta E = ? \text{ (Nil) ?}$

$Q = \Delta E + W$
 $350 = \Delta E + 0$
 $\Delta E = 350 \text{ kW}$
(b-c)

Process C-D

$$C-D: Q = -35$$

$$W = \text{nil}$$

$$\Delta E = -610$$

$$\text{Sol: } Q = \Delta E + W$$

$$-35 = -610 + W$$

$$W_{(c-d)} = 575 \text{ kW}$$

Process D-a

No given data providing so we take
All heat transfer is -200 kJ

$$(\sum Q) = -200 \text{ kJ}$$

The system completes 2 cycles/sec so

$$\sum Q = -200 \times 2 = -400 \text{ kW}$$

$$\left(\text{kJ} \times \frac{1}{\text{sec}} \right)$$

$$\sum Q = -400 \text{ kW} = Q_{(a-b)} + Q_{(b-c)} + Q_{(c-d)} + Q_{(d-a)}$$

We take heat transfer from table

$$-400 = 0 + 350 - 35 + Q_{d-a}$$

$$Q_{d-a} = 715 \text{ kW}$$

Also $\oint dE = 0$ since cyclic integral of any
Property is zero.

$$\Delta E_{(a-b)} + \Delta E_{b-c} + \Delta E_{c-d} + \Delta E_{d-a} = 0$$

$$\overset{-715}{-36} + \overset{\text{Find out}}{350} - \overset{-715}{610} + \Delta E_{d-a}$$

$$\Delta E_{d-a} = 296 \text{ kW}$$

In Process D-a

$$Q = \Delta E + W$$

$$-715 = 296 + W$$

$$W_{(D-a)} = -1011 \text{ kW}$$

Process	Q	W	ΔE
a-b	0	36	-36
b-c	350	0	350
c-d	-35	575	-610
D-a	-715	-1011	296
Total	$\sum Q = -400$	$\sum W = -400$	$\sum \Delta E = 0$

Non-Flow Process

1.38

One kg of Ideal gas is heated from 18°C to 93°C assuming $R = 264 \text{ J/kg K}$ ratio of Specific heat 1.18 for the gas and heat transfer of 160 kJ find (i) Sp. heat (ii) change in internal energy (iii) change in enthalpy (iv) work transfer

Given:

$$m = 1 \text{ kg}$$

$$T_1 = 18 + 273 = 291 \text{ K}$$

$$T_2 = 93 + 273 = 366 \text{ K}$$

$$R = 0.264 \text{ kJ/K}$$

$$\gamma = \frac{C_p}{C_v} = 1.18$$

$$Q = 160 \text{ kJ}$$

Sol:

Find C_p & C_v

$$\frac{C_p}{C_v} = \gamma = 1.18$$

$$C_p - C_v = R = 0.264$$

$$1.18 C_v - C_p = 0.264$$

$$C_v = 1.4667 \text{ kJ/kg K}$$

$$C_p = C_v + R = 1.4667 + 0.264$$

$$= 1.7307 \text{ kJ/kg K}$$

$$C_p = 1.7307$$

$$C_v = 1.4667$$

To find ΔU

$$\Delta U = m C_v [T_2 - T_1] = 1 \times 1.4667 [366 - 291]$$

$$\Delta U = 110.0025 \text{ KJ}$$

To find ΔH

$$\Delta H = m C_p [T_2 - T_1] = 1 \times 1.7307 [366 - 291]$$

$$\Delta H = 129.8025 \text{ KJ}$$

To find W

According to first law of thermodynamics

$$Q = \Delta U + W$$

$$160 = 110.0025 + W$$

$$W = 49.9975 \text{ KJ}$$

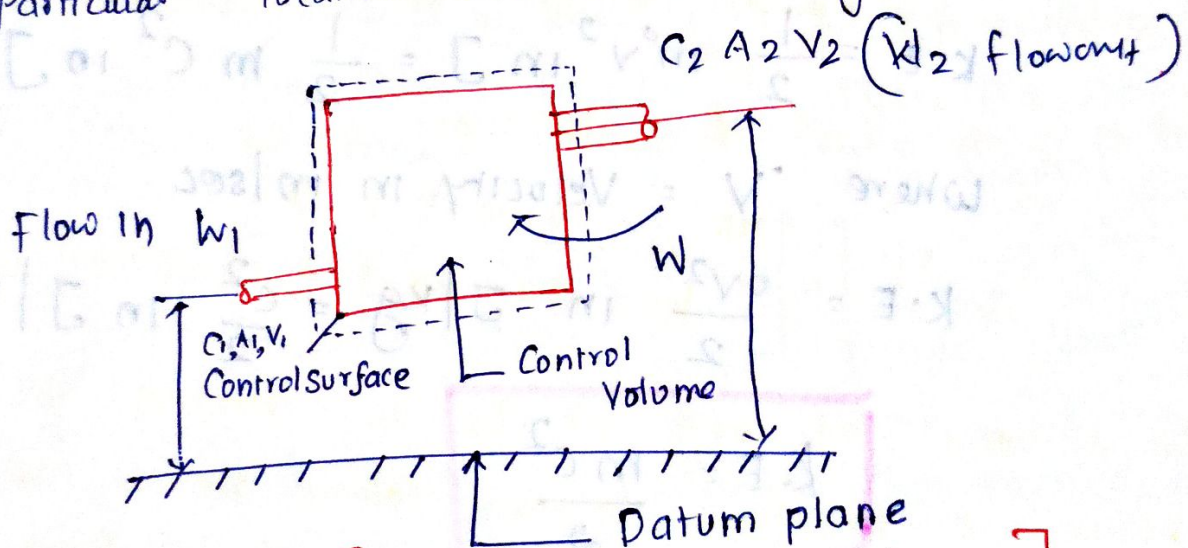
In a vessel of 10 kg of O_2 is heated in a reversible non flow constant volume process, so that the pressure of O_2 is increased two times that of initial value. The initial temperature is 20°C . Calculate final temp, change in internal energy, change in enthalpy and heat transfer. Take $R = 0.259 \text{ kJ/kg}^\circ\text{C}$ and $C_v = 0.652 \text{ kJ/kg}^\circ\text{C}$ for oxygen

Steady Flow process :

1.39

Thermodynamic ~~process~~ properties which have a fixed value at particular location and does not vary with time is said to be in steady state.

• In steady flow process the fluid enters at the inlet and goes out through the outlet without the accumulation of mass or energy inside the control and the thermodynamic properties has fixed value at a particular location and does not vary with time.



SFEE (Steady Flow Energy Equation)

Potential Energy (P.E)

It is energy possessed by any system [or body] by virtue of its height (position above the ground level)

$$P.E = mgZ \text{ or } mgh \text{ in J}$$

where

m - be mass of the system in kg

g - be acceleration due to gravity in m/s^2

Z - be the height of the system above from datum in m (or) ht above the ground level

$$P.E = g Z \text{ in J/kg}$$

(2) Kinetic energy:

It is energy possessed by any system by virtue of its velocity

$$K.E = \frac{1}{2} m v^2 \text{ in J} = \frac{1}{2} m c^2 \text{ in J}$$

where v = Velocity in m/sec

$$K.E = \frac{v^2}{2} \text{ in J/kg} = \frac{c^2}{2} \text{ in J/kg}$$

$$K.E = \frac{m c^2}{2}$$

~~To difference~~

(3) Pressure Energy:-

The energy possessed by any system by virtue of its pressure

$$Pv = \frac{N}{m^2} \times \frac{m^3}{kg} = \frac{N \cdot m}{kg} = J/kg$$

The above equation known as Steady Flow energy equation [SFEE]. The above equation represents the flow per unit of mass of the working substance [J/kg]. When the equation is multiplied by mass of the working substance through, then all terms will represent the energy flow per unit time

The above equation becomes

$$m \left[gz_1 + \frac{C_1^2}{2} + h_1 + Q \right] = m \left[gz_2 + \frac{C_2^2}{2} + h_2 + W \right] \quad (3)$$

If the values of Q and W in kJ/kg, and h1 and h2 are substituted in kJ/kg then the above equ becomes

heat Q work W kJ/kg
so multiply by 1000

$$m \left[\frac{gz_1}{1000} + \frac{C_1^2}{2000} + h_1 + Q \right] = \left[\frac{gz_2}{1000} + \frac{C_2^2}{2000} + h_2 + W \right]$$

If Q & W are already in kW and h1 & h2 substituted in kJ/kg, then above equation becomes

$$m \left[\frac{gz_1}{1000} + \frac{C_1^2}{2000} + h_1 \right] + Q = m \left[\frac{gz_2}{1000} + \frac{C_2^2}{2000} + h_2 \right] + W$$

Note: In steady flow system, the mass rate of the working substance is given by

where

The mass is represented in kg/s

A_1 and A_2 are areas of cross section at entry and exit in m^2

Important formula - Open system: (Steady Flow Energy Equation)
S.F.E.E

(1) S.F.E.E / unit mass is given by

$$gz_1 + \frac{C_1^2}{2} + h_1 + Q = gz_2 + \frac{C_2^2}{2} + h_2 + W$$

(2) S.F.E.E to boiler

$$Q = h_2 - h_1$$

(3) S.F.E.E to Condenser

$$Q = h_2 - h_1$$

(4) Nozzle SFEE, $\frac{C_2^2 - C_1^2}{2} = h_1 - h_2$

$$\text{Velocity } C_2 = \sqrt{2(h_1 - h_2) + C_1^2} \text{ m/s}$$

(5) If Initial Velocity is neglected

$$C_2 = \sqrt{2(h_1 - h_2)}$$

(6) for turbine:

$$W = h_1 - h_2$$

(6) For rotary compressor: $W = h_2 - h_1$

(7) For reciprocating " : $W = Q + [h_2 - h_1]$

A steady flow process 125 kJ of work is done by each kg of working fluid. The Sp. Volume, Velocity & Pressure of working fluid at inlet are $0.4 \text{ m}^3/\text{kg}$, 15.5 m/s and 6 bar respectively. The inlet is 31 m above the ground and the exhaust pipe is at the ground level. The discharge conditions of the working fluid are $0.64 \text{ m}^3/\text{kg}$, 1 bar and 263 m/s . The total heat loss b/w inlet and discharge is 8.7 kJ/kg of fluid. In flowing through this apparatus, does the Sp Internal energy increase or decrease and how much?

G.P.:

$$W = 125 \text{ kJ/kg}$$

$$V_1 = 0.4 \text{ m}^3/\text{kg}$$

$$C_1 = 15.5 \text{ m/s}$$

$$P_1 = 6 \text{ bar} = 600 \text{ kN/m}^2$$

$$Z_1 = 31 \text{ m}$$

$$Z_2 = 0$$

$$V_2 = 0.64 \text{ m}^3/\text{kg}$$

$$C_2 = 263 \text{ m/s}$$

$$P_2 = 1 \text{ bar} = 100 \text{ kN/m}^2$$

$$Q = -8.7 \text{ kJ/kg}$$

To find Internal energy Increase or decrease how?

Solution:

The steady flow energy eq

$$gz_1 + \frac{C_1^2}{2} + u_1 + P_1 V_1 + Q = gz_2 + \frac{C_2^2}{2} + P_2 V_2 + W$$

$$gz_1 + \frac{C_1^2}{2} + u_1 + P_1 V_1 + Q = gz_2 + \frac{C_2^2}{2} + u_2 + P_2 V_2 + W$$

$$u_1 - u_2 = g(z_2 - z_1) + \frac{C_2^2 - C_1^2}{2} + (P_2 V_2 - P_1 V_1) + W - Q$$

$$u_1 - u_2 = 9.81 [0 - 31] \times 10^{-3} + \frac{[263^2] - [15.5]^2}{2} \times 10^{-3} +$$

$$[100 \times 0.64 - 600 \times 0.41] + 125 - (-8.7)$$

$$u_1 - u_2 = -0.304 + 34.46 - 182 + 125 + 8.7$$

$$u_1 - u_2 = -14.14 \text{ kJ/kg}$$

300°C. The entrance velocity is 2400 m/min and exit velocity is 1200 m/min. During the process, 50000 kJ/hr of heat is transferred to the control volume and rise in enthalpy is 8 kJ/kg. Calculate the power developed.

G.D: $m = 50 \text{ kg/min} = \frac{50}{60} = 0.83 \text{ kg/s}$

$$P_1 = 2 \text{ bar}$$

$$T_1 = 100^\circ\text{C} = 373 \text{ K}$$

$$z_1 = 150 \text{ m}$$

$$P_2 = 10 \text{ bar}$$

$$T_2 = 373 \text{ K}$$

$$C_1 = 2400 \text{ m/min} = \frac{2400}{60} = 40 \text{ m/s}$$

$$C_2 = 1200 \text{ m/min} = \frac{1200}{60} = 20 \text{ m/s}$$

$$Q = 50000 \text{ kJ/hr} = \frac{50000}{3600} = 13.89 \text{ kJ/s}$$

To find

Power developed P

Sol:

S.F.E.E

$$gz_1 + \frac{C_1^2}{2} + \rho_1 V_1 + Q = gz_2 + \frac{C_2^2}{2} + \rho_2 V_2 + W$$

$$W = g(z_1 - z_2) + \frac{C_1^2 - C_2^2}{2} + (\rho_1 - \rho_2) + Q$$

$$W = 9.81 [100 - 150] + \frac{(40^2 - 20^2)}{2} + 8 \times 10^3 + 13.89 \times 10^3$$

$$W = 5999.5 \text{ J/kg}$$

$$W = 6 \text{ kJ/kg}$$

Power developed $P = W \times \text{Mass}$

$$= 6 \times 0.83$$

$$= 4.98 \text{ kJ/s}$$

$$= 4.98 \text{ kW} //$$

1.44

A boiler produce Steam from Water at 35°C . The enthalpy of Steam is 2675 kJ/kg . Calculate the heat transferred per kg. The sp. heat capacity of water is 4.19 kJ/kg K . Neglect the potential and kinetic energies.

G. D :

$$T_w = 35^{\circ}\text{C} = 35 + 273 = 308 \text{ K}$$

$$h_2 = 2675 \text{ kJ/kg}$$

$$C_{pw} = 4.19 \text{ kJ/kg K}$$

To find

Heat transferred Q

Sol :

Enthalpy of feed water

$$h_1 = C_{pw} \times T_w = 4.19 \times 308 = 1290.52 \text{ kJ/kg}$$

SFEE for boiler, heat transferred Q

$$Q = h_2 - h_1$$

$$Q = 2675 - 1290.52$$

$$Q = 1384.48 \text{ kJ/kg}$$