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NSRIT NADIMPALLI SATYANARAYANA RAJU INSTITUTE OF TECHNOLOGY
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NAAC 'A' GRADE
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SONTYAM, Pendurthi - Anandapuram Highway, Visakhapatnam - 531173, web: www.nsrit.edu.in
DEPARTMENT OF MECHANICAL ENGINEERING

THERMODYNAMICS LECTURE NOTES
II YEAR I SEMESTER: R-16 REGULATION

PREPARED BY Mr.S.SANYASIRAO
ASSISTANT PROFESSOR

UNIT – I

Introduction: Basic Concepts : System, boundary, Surrounding, control volume, Universe, Types of Systems, Macroscopic and Microscopic viewpoints, Concept of Continuum, Thermodynamic Equilibrium, State, Property, Process, Cycle – Reversibility – Quasi – static Process, Irreversible Process, Causes of Irreversibility – Energy in State and in Transition, Types, Work and Heat, Point and Path function. Zeroth Law of Thermodynamics –Concept of Temperature – Principles of Thermometry –Reference Points – Const. Volume gas Thermometer –Scales of Temperature, Ideal Gas Scale – PMM I

UNIT II

Joule's Experiments – First law of Thermodynamics – Corollaries – First law applied to a Process – applied to a flow system – Steady Flow Energy Equation. PMM I ,Throttling and free expansion processes – deviations from perfect gas model – vander Waals equation of state – compressibility charts – variable specific heats – gas tables.

UNIT – III

Limitations of the First Law – Thermal Reservoir, Heat Engine, Heat pump,Parameters of performance, Second Law of Thermodynamics, Kelvin-Planck and Clausius Statements and their Equivalence / Corollaries, PMM of Second kind, Carnot's principle, Carnot cycle and its specialties, Thermodynamic scale of Temperature, Clausius Inequality, Entropy, Principle of Entropy Increase – Energy Equation, Availability and Irreversibility –Thermodynamic Potentials, Gibbs and Helmholtz Functions, Maxwell Relations – Elementary Treatment of the Third Law of Thermodynamics.

UNIT IV

Pure Substances, p-V-T- surfaces, T-S and h-s diagrams, Mollier Charts, Phase Transformations – Triple point at critical state properties during change of phase, Dryness Fraction – Clausius – Clapeyron Equation Property tables. Mollier charts – Various Thermodynamic processes and energy Transfer – Steam Calorimetry.

UNIT – V

Mixtures of perfect Gases – Mole Fraction, Mass friction Gravimetric and volumetric Analysis – Dalton's Law of partial pressure, Avogadro's Laws of additive volumes – Mole fraction, Volume fraction and partial pressure, Equivalent Gas const. And Molecular Internal Energy, Enthalpy, sp. Heats and Entropy of Mixture of perfect Gases and Vapour, Atmospheric air - Psychrometric Properties – Dry bulb Temperature, Wet Bulb Temperature, Dew point Temperature, Thermodynamic Wet Bulb Temperature, Specific Humidity, Relative Humidity, saturated Air, Vapour pressure, Degree of saturation – Adiabatic Saturation, Carrier's Equation – Psychrometric chart.

UNIT - VI

Power Cycles : Otto, Diesel, Dual Combustion cycles, Sterling Cycle, Atkinson Cycle, Ericcson Cycle, Lenoir Cycle Description and representation on P–V and T-S diagram, Thermal Efficiency, Mean Effective Pressures on Air standard basis – comparison of Cycles.

Refrigeration Cycles : Brayton and Rankine cycles – Performance Evaluation – combined cycles, Bell- Coleman cycle, Vapour compression cycle-performance Evaluation.

UNIT – I

Introduction: Basic Concepts:

Thermodynamics : "Thermi" literally means heat and " Dynamics " is nothing but Power, So thermodynamics is nothing but conversion of heat into power

Applications of the thermodynamics :-

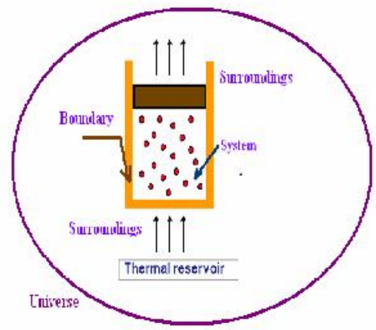
- I.C Engines
- Power plants

- E.C Engines
- Refrigeration and Air conditioning systems
- Jet engines
- Automobiles
- Rockets,turbines,compressors, Etc

Thermodynamic System (System): 2016-R

- It is the region or space on which the attention is focused for study.
- System may be quantity of steam, mixture of vapour and gas or an I.C engine cylinder with its contents
- System is enclosed by a boundary

Boundary:



- Boundary separates the system from the surroundings
- The boundary may be real or imaginary, fixed or movable
- If Nozzle is a system there will not be any real boundary at its ends. In such a case we need to assume the boundary known as imaginary.
- If any gas in a cylinder is bounded by a piston, whose upward movement is Restricted by the stoppers is subjected to external heat source then the gas Will ties to expand. But the stoppers will not allow the expansion in such A case the boundary is a fixed boundary.

Surroundings : Any thing outside the boundary is called its surroundings

Universe: A system, its boundary and the surrounding are combindly known as universe.

Types of system:

(Explain types of systems 2015-RJ)&2016-R

(What is the difference between closed system and open system? Give example 2015-S)

Definition		Work	Heat	Mass
Isolated system		No	No	No
Closed system	Also called **Control Mass**	Yes	Yes	No
Open system	Also called **Control Volume**	Yes	Yes	Yes

A thermodynamic system can be classified into

i. Open system
ii. Closed system
iii. Isolated system

Open system: It is a thermodynamic system which allows both mass and energy to cross the boundary. It is also known as flow process (or) control volume.

Ex:- Turbines, compressor, nozzles, I.C engines, cooking in pot ,etc.,

Closed system: It is a thermodynamic system which does not allow mass to cross the boundary but the energy may cross the boundary. It is also known as control mass (or) Non flow process.

Ex:- Refrigeration cycle, closed cycle gas turbine power plant ,cooking in pressure cooker, etc

Isolated System: It is a thermodynamic system which does not allow either mass (or) energy to cross the boundary.

Ex'- Universe, Thermal flask with ice cubes, adiabatic engine,etc.,

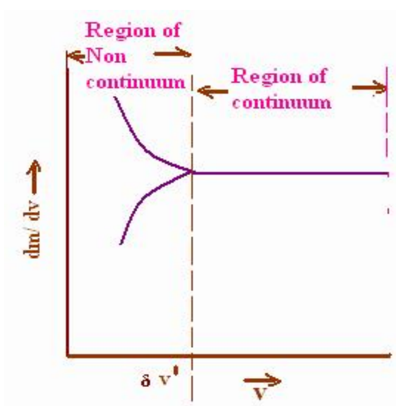
Control Volume: It is a property of selected region in space is nothing but control volume. This allows the mass flow. An open system is nothing but a control volume.Exp:Nozzles,Diffusers,Turbines,Compressors, Heat Exchanger,etc.**2016-R**

Macroscopic approach and microscopic view of approach:

(What do you understand by macroscopic and microscopic viewpoints? 2015-S, 2017-S,2015-RD)

S.no	Macro scopic approach	Micro scopic approach
1.	Studying a thermodynamic system without bothering the events occurring at molecule level.	Studying the system by considering the events at molecular level.
2.	The simple mathematic relations are enough to analyze the system.	A simple mathematic relations are not enough to analyze the systems
3.	In case of macroscopic approach we can measure a thermodynamic property in laboratory.	It is very difficult to measure in laboratory.
4.	Simple mathematical data is enough to study the system.	Along with the mathematical data statistical data is also essential.
5.	This study is known as classical thermo dynamics.	This study is known as statistical thermodynamics.

Concept of Continuum: (Explain the concept of continuum 2015-RJ)



- The concept of continuum is a kind of idealization of the continuous description of matter where the properties of the matter are considered as continuous functions of space variables.

- Although any matter is composed of several molecules, the concept of continuum assumes a continuous distribution of mass within the matter or system with no empty space, instead of the actual mixing of separate molecules.
- Every substance is made from own molecules. In case of gaseous substance the molecules are widely spreader.
- Consider a volume of dV around the point P which consists of a mass of dM. In the region of continuum.
- The ratio of dM/dV is constant even though there is a change in volume. It will be maintain up to the limit of volume dV.
- It indicates that the system is a continues up to this volume only.
- If the volume is still decrease beyond SV, some molecules may escape into the surroundings and dM/dV may decrease.
- Otherwise with considerable decrease in volume the SM/SV may increase that indicates that the substance is not continuum in the molecule region.
- In continuum approach, fluid properties such as density, viscosity, thermal conductivity, temperature, etc. can be expressed as continuous functions of space and time.
- For example density at a point is normally defined as $\rho = \lim_{\Delta\forall \to 0}\left(\frac{m}{\Delta\forall}\right)$
- is the volume of the fluid element and m is the mass

Thermodynamic Equilibrium: (Explain about thermodynamic equilibrium. 2015-RJ)
(Discuss about thermodynamic equilibrium. 2015-RD)

A system is said to be under thermodynamic equilibrium if it satisfies the following condition of the equilibrium.

- Mechanical equilibrium
- Chemical equilibrium
- Thermal Equilibrium

Mechanical Equilibrium: A system is said to be under mechanical equilibrium if there is no unbalanced force with in the system (or) between system and surroundings.

Chemical Equilibrium: The system is said to be under chemical equilibrium if there is no chemical reaction within the system or system and surroundings.

Thermal equilibrium: The system is said to be under thermal equilibrium if it is separated from the surroundings by a diathermal wall or adiabatic wall.

Note:- Sometimes the system may not be under chemical equilibrium but it is under mechanical and thermal equilibrium such a condition is known as **meta stable equilibrium.**

Property: It is the characteristic of the system . There are eight properties.

1. Pressure (p)
2. Volume (v)
3. Temperature (T)
4. Internal energy(U)
5. Enthalaphy (h)
6. Entropy(S)
7. Gibbs function(G)
8. Helmotz's function.(H)

Types of properties:-

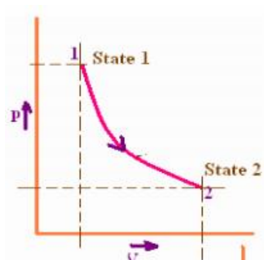
(What are intensive and extensive properties? 2015-S)

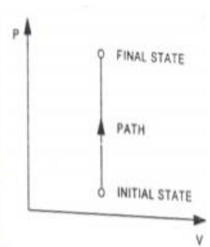
1) Intensive property
2) Extensive property

Intensive property or Intrinsic properties:- These properties are independent of mass of the system.
Ex: pressure p and temperature T, ,specific gravity, ,surface tension, thermal conductivity etc.
Intensive property is the value of an extensive property per unit mass of system. e.g: specific volume, density(v, ρ).

Extensive property or Extrinsic properties:-These properties are dependent of mass of the system
Ex: Volume, energy ,mass, enthalpy *H,* entropy S.

(Distinguish between terms Change of 'state', 'path', and 'process'?2015-S), 2015-RJ





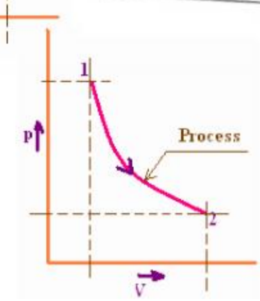
State :

- State is nothing but the physical condition of the system.
- To define the state at least two properties are essential.

Path: The series of states through which the system passes during change of state is called Path

Process:

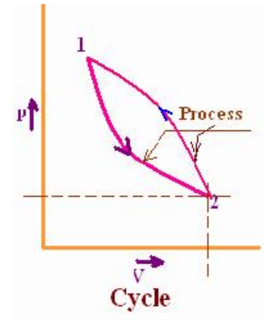
- A process is nothing but the change of state.
- A substance which is being heated in a closed cylinder undergoes a non-flow process Closed systems undergo non-flow processes.
- A process may be a flow process in which mass is entering and leaving through the boundary of an open system.



Examples of thermodynamic processes

- Expansion or compression of a gas

- Expansion of steam through a nozzle
- Conversion of water into steam



Cycle : Thermodynamic cycle (or) cyclic process:-

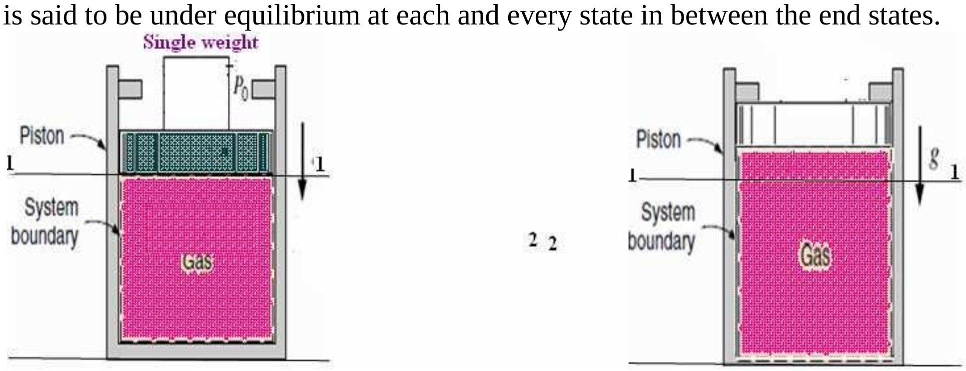
- A cycle is nothing but sequence of thermodynamic process
- In which the end states are identical
- The area under P-V diagram will give the work done.
- Internal combustion engines, gas turbines, steam engines, steam turbines, air or gas compressors, refrigeration devices etc. are all thermodynamic devices which work on thermodynamic cycles.

Example: water (steam) that circulates through a steam power plant under goes a cycle

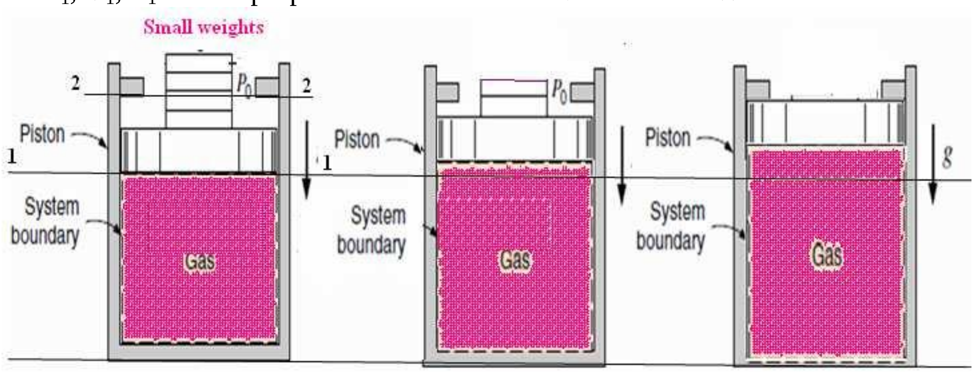
Quasi static process: (Explain about Quasi static process 2015-RJ)& 2016-R

(What is quasi-static process? Explain its characteristic features. 2015-RD)

Quasi literally means almost so the quasi static process is the process in which the system is said to be under equilibrium at each and every state in between the end states.



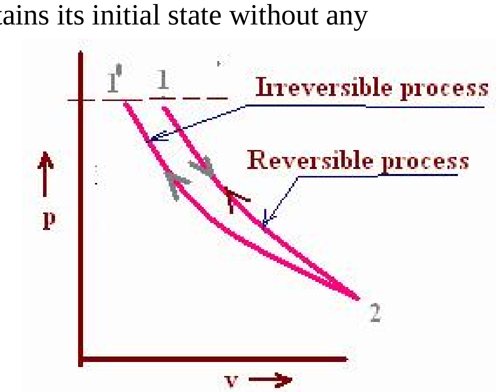
- Consider certain amount of gas in a cylinder which is bounded by a piston when the load W is acting on the piston the system is under equilibrium and is known as initial state of equilibrium.
- Let P_1, V_1, T_1 are the properties at this condition. If the load W is removed suddenly the pressurized gas will ties



- To push out the piston the upward movement of piston is restricted by stoppers which are provided at the other end of cylinder over a finite period of time again the system attains equilibrium condition knows as second stage of equilibrium condition.
- Even though the system is under equilibrium at stage (1) and (2), it may not be under equilibrium in b/w these two states.
- Consider the same type of system which is subjected to no. of small loads. At this stage the system is under equilibrium. If one small load is removed there may not be any appreciable change in properties.
- So, we can say that the system is under equilibrium i.e., there may not be any change in equilibrium with every removal of small load.
- So, the system is said to be under equilibrium at every states and the process will becomes a quasi static process.

Note:- In real life no process is a quasi static process.

Reversible process : A reversible process is a process in which the System attains its initial state without any effect on the rest of the environment. **Exp: spring mass system**



1-2 → process

2-1 → Reversible process

A process can become reversible:

- If there is no involvement of friction (can also be called as ideal process)
- If it is a quasi static process
- If the process is very slow

Irreversible process : It is a process in which the initial state cannot be attained. **Exp: water fall from top side, sun's energy, hot cup of copy**

Note:- In real life every process is irreversible.

Causes for irreversibility: Generic types of irreversibilities are due to;

- Friction,
- Electrical resistance,
- Inelastic solid deformations,
- Free expansion
- Heat transfer through a finite temperature difference,
- Non equilibrium during the process, etc.

Energy: It is the capacity to do work units- joules (or) kilojoules.

Types of Energy:-

1) Static form of energy **(Energy in state)**
2) Dynamic form of energy **(Energy in Transission)**

Static form of energy (Energy in state): It is the quantity of energy which is stored within the system.

Ex: potential energy kinetic energy, energy stored in full

Dynamic form of energy (Energy in Transission):It is the form of energy which cannot be stored within the system i.e., energy will cross the boundery of system. Also called as energy Interaction (or) Energy transition.

Ex: Heat and work are energy in transition .

(Distinguish between Heat and Work? 2015-RJ)

Heat :

- It is the form of energy in transition which may cross the boundary by the virtue of difference in temperature.
- Denoted by Q.
- Units – Joules (or) kilo joules
- In adiabatic process there will not be any heat inflow or outflow.
- Heat added to the system is always positive
- And heat rejected by the system is always negative.

Work:

- If energy is crossing the boundary and if it is not heat then it is nothing but work.
- Work input to the system is negative.
- Work developed by system is positive.
- Units-Joules (or) Kilojoules

Other forms of works such as :

(i) **Spring work** (Strain energy) — $W = \int F\,dy$; F – Force ; y = displacement; $F = ky$; k – spring constant

(ii) **Stretched wire or rod : beam : torsion bar** (Strain energy) — $W = \int F\,dy$ or $\int T\,d\theta$ F-Force; Y – displacement; T – torque ; θ - angular displacement

(iii) **Surface tension** — $W = \int \sigma\,dA$; σ - surface tension, A – area

(iv) **Electrical work** — W = VI watts or joules/second; V – emf volts ; I – current ampere; $W = \int V\,dQ$: V – emf , Q – charge in coulombs

(Distinguish between Path function and Point function. 2015-RJ)& 2016-R

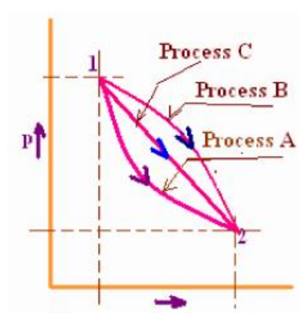
Point function:

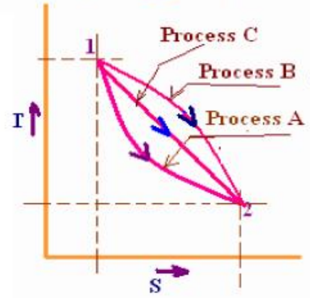
- The thermodynamic event which is the function of end states is called point function
- Ex: temperature
- All the thermodynamic properties are point functions.

Path function :

- A thermodynamic event which is a function of the path executed by the process.
- Ex: heat, work

Show Work is a path function: 2016-R





- Heat and work are in exact differentials.
- $\int_1^2 dw = w_2 - w_1$
- Consider three different processes a,b and c between the same end states.
- As you know the area under P-V diagram will give the work done.
- $W_A < W_B < W_C$
- Because the area under A < area under B < area under C from above equation it is evident that even though the end states are same for all the three processes the work done is different from process
- to process. i.e., the work done is independent of end state and it will dependent on the path of the process.
- Therefore **work is a path function and not a property.**

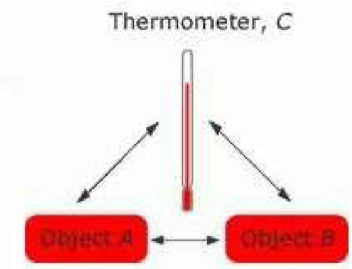
Heat is a path function:

(Show that heat transfer is a path function and not a property. 2015-RD)

- The area under TS diagram will give heat transfer.
- The area under process A is less than the area under process B is less than the area under
- process C, even though the end States are identical
- $Q_A < Q_B < Q_c$
- From the above equation we can say that heat transfer will depend on a path of a process

Zeroth law of thermo dynamics:-

- If two bodies are in thermal equilibrium with a third body separately then the all the three bodies are in thermal equilibrium with one another.
- Zeroth law is basis for temperature measurement.
- Consider certain quantity of liquid in a vessel. Let A is the liquid, B is the Glass bulb and C is the mercury.
- T_A is the temperature of the liquid.
- T_B is the Bulb temperature.
- T_C is the mercury temperature.
- The inner side of the monometer, over a finite period of time the glass bulb will attain the thermal equilibrium condition with the liquid i.e., T_A+T_B
- After sometime the mercury in will attain the thermal equilibrium condition with respect to the glass bulb
- $T_B = T_C$ &$T_A = T_C$
- $T_A = T_B = T_C$
- i.e., the mercury indicates the temperature of the liquid. At this incident. $T_A = T_B = T_C$
- Which satisfies the zeroth law of thermo dynamics



Zeroth law of thermodynamics

CONCEPT OF TEMPERATURE AND EQUALITY OF TEMPERATURE:

- Consider for example, that we touch a block of metal which is at 100^o.
- We conclude that it is hotter than a block of ice.
- When we touch the hot block, our hand is receiving heat energy from the block, whereas if we touch the cold block of ice we are losing heat energy.
- This concept of temperature is based upon energy transfer process. otherwise we may say heat exchange process.
- Suppose our hand touches a body which is in the same thermal state as ours then we should experience neither "hot" nor "cold" feeling.
- Therefore we can conclude no heat exchange will take place between the two.
- This enable us to define equality of temperature i.e. there is something equal to the bodies or system which we may call as temperature.

Thermometry:-

1) It is the art of measuring temperature.
2) Ice point :This is limit of temperature where the solid and liquid states are in the under equilibrium.
3) Steam point: It is limit of temperature where a liquid and vapour under thermal equilibrium.

Thermometric property:- It is the property which is influenced by the temperature.

Ex: length, resistance. Pressure, volume

Two reference point temperature scale:-

Let T is the temperature, x is the thermometric property , $T \propto x$

$$T = ax \quad \rightarrow (1)$$

Here 'a' is constant

At the ice point the equation becomes $T_1 = ax_1 \quad \rightarrow (2)$

Similarly at the steam point $T_2 = ax_2 \quad \rightarrow (3)$

To find the temperature at the thermometric property, at x

(3) / (1) $\rightarrow T_1 / T = x_1 / x \quad \rightarrow (4)$

(2) / (1) $\rightarrow T_2 / T = x_2 / x \quad \rightarrow (5)$

On subtracting (5) from (4) (4) - (5) $(T_2 - T_1) / T = (x_2 - x_1) / x$

Scales of Temperature : Some two point temperature scales:-

1) Celsius scale
2) Fahrenheit scale
3) Reamer Scale
4) Kelvin Scale

<u>Celslus scale:</u>

- Ice point-0^0C
- Steam point-100^0C
- Scale is divided into 100 equal divisions.

Fanrenheat scale:-

- Ice point-32F
- Steam point – 212F
- Scale is devided into 180 equali divisions

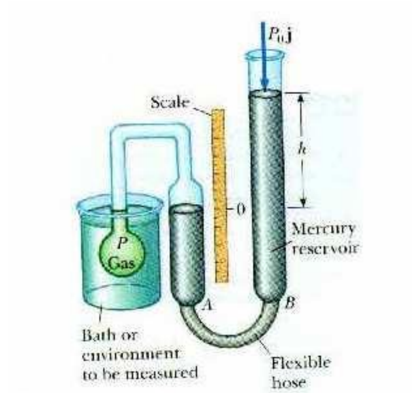
Reamur scale:-

- Ice point-80R
- Steam point-80R
- Scale is divided into 80 equal divisions

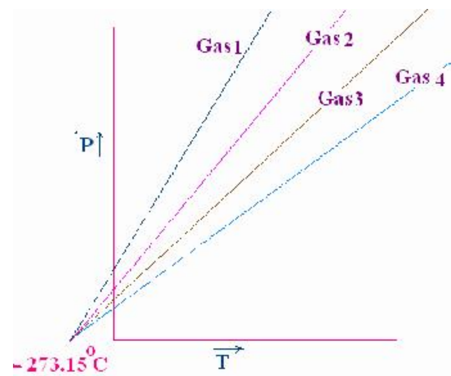
Constant volume gas thermometer:-

(With the help of neat sketch explain the working of constant pressure gas thermometer. (8M)2015-S)
(Describe the working of constant volume gas thermometer with a sketch? (8M) 2015-RJ)& 2016-R

- It consists of two vertical grass tubes connected By a flexible tube.
- One end of the glass tube is exposed to atmosphere and the other end is in Communication with the gas bulb to a capillary tube.
- The gas bulb is filled with any gas like oxyzen, nitrozed, hydrozen and the nanometer is filled with mercury.
- Let Po is the atmospheric pressure
- p the density of manometric liquid H is the a differential head
- Whenever the gas bulb is exposed to any temperature T (which is unknown) then the pressure P is equals to atmospheric pressure + pressure due to differential head.
- $P = P_0 + pgh$
- Now expose the gas bulb to the triple point temperature (273.16k) At this instant pressure acting on the gas $P_{TRP} = P + Rgh$
- We know that T œ P
- T = C P
- T/P=constant
- T_{trip} / P_{trip} = constant
- $T / P = T_{triple} / P_{trip}$
- $T = P / P_{triple} \times T_{triple}$
- If the a constant volume gas thermometer is operated with different gasses inside the gas bulb at different instances the variation in temperature w.r to pressure is shown in fig.



Constant volume gas thermo meter



Ideal gas temperature scale:

(What do you understand by Ideal gas temperature scale? 2015-S)& 2016-R

- The temperatures on this scale are measured using a constant volume thermometer. Based on the principle that at low pressure, the temperature of the gas is proportional to its pressure at constant volume. The relationship between the temperature and pressure of the gas in the vessel can be expressed as
  $T = a + b.P$
- Where the values of the constants a and b for a gas thermometer are determined experimentally. Once a and b are known, the temperature of a medium can be calculated from the relation above by immersing the rigid vessel of the gas thermometer into the medium and measuring the gas pressure.
- Ideal gas temperature scale can be developed by measuring the pressures of the gas in the vessel at two reproducible points (such as the ice and steam points) and assigning suitable values to temperatures those two points. Considering that only one straight line passes through two fixed points on a plane, these two measurements are sufficient to determine the constants a and b in the above equation. If the ice and the steam points are assigned the values 0 and 100 respectively, then the gas temperature scale will be identical to the Celsius scale. In this case, the value of the constant a (that corresponds to an absolute pressure of zero) is determined to be –273.150C when extrapolated.
- The equation reduces to T = bP, and thus we need to specify the temperature at only one point to define an absolute gas temperature scale. Absolute gas temperature is identical to thermodynamic temperature in the temperature range in which the gas thermometer can be used. We can view that thermodynamic temperature scale at this point as an absolute gas temperature scale that utilizes an ideal gas that always acts as a low-pressure gas regardless of the temperature.

PMM I: **(What is PMM1? 2015-RD)& 2016-R**

A machine which produce works continuously without consuming any other form of energy is called PMM1.

****FIRST SOLVE ALL THE PROBLEMS FROM NOTE BOOK****

******THEN REFER NEXT PAGE FOR ADDITIONAL PROBLEMS TO PRACTICE******

ssraome@nsrit.edu.in

*****Prepared by Mr.Sanyasi Rao Surada/9292556602/8074819124/ ssraome.nsrit@gmail.com*****

Q2.5 **The temperature t on a thermometric scale is defined in terms of a property K by the relation**

$$t = a \ln K + b$$

Where a and b are constants.
The values of K are found to be 1.83 and 6.78 at the ice point and the steam point, the temperatures of which are assigned the numbers 0 and 100 respectively. Determine the temperature corresponding to a reading of K equal to 2.42 on the thermometer.

(**Ans.** 21.346°C)

Solution:

$$t = a \ln K + b$$

$$0 = a \times \ln 1.83 + b \quad \text{... (i)}$$

$$100 = a \times \ln 6.78 + b \quad \text{... (ii)}$$

Equation {(ii) – (i)} gives

$$a \cdot \ln \cdot \left(\frac{6.78}{1.83}\right) = 100$$

or $a = 76.35$

$\therefore$ $b = -a \times \ln 1.83$

$= -46.143$

$\therefore$ $t = 76.35 \ln k - 46.143$

$\therefore$ $t^{*} = 76.35 \times \ln 2.42 - 46.143$

$= 21.33°C$

Q2.6 **The resistance of the windings in a certain motor is found to be 80 ohms at room temperature (25°C). When operating at full load under steady state conditions, the motor is switched off and the resistance of the windings, immediately measured again, is found to be 93 ohms. The windings are made of copper whose resistance at temperature t°C is given by**

$$R_t = R_0 [1 + 0.00393\, t]$$

Where R_0 is the resistance at 0°C. Find the temperature attained by the coil during full load.

(**Ans.** 70.41°C)

Solution:

$$R_{25} = R_0 [1 + 0.00393 \times 25]$$

$\therefore$ $$R_0 = \frac{80}{[1 + 0.00393 \times 25]} = 72.84\ \Omega$$

$\therefore$ $93 = 72.84 \{1 + 0.00393 \times t\}$

or $t = 70.425°C$

Q3.4 **A mass of 1.5 kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa for which pv = constant. The initial density of air is 1.16 kg/m³. Find the work done by the piston to compress the air.**

(**Ans.** 251.62 kJ)

Solution: **For quasi-static process**

Work done $= \int p dV$ [given $pV = C$

$= p_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V}$ $\therefore$ $p_1 V_1 = pV = p_2 V_2 = C$

$= p_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$ $\therefore$ $p = \frac{p_1 V_1}{V}$

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

$= 0.1 \times 1.2931 \times \ln\left|\frac{0.1}{0.7}\right|$ MJ given $p_1 = 0.1$ MPa

$= 251.63$ kJ $V_1 = \frac{m_1}{\rho_1} = \frac{1.5}{1.16}\ m^3$

$p_2 = 0.7$ MPa

Q3.6 **A single-cylinder, double-acting, reciprocating water pump has an indicator diagram which is a rectangle 0.075 m long and 0.05 m high. The indicator spring constant is 147 MPa per m. The pump runs at 50 rpm. The pump cylinder diameter is 0.15 m and the piston stroke is 0.20 m. Find the rate in kW at which the piston does work on the water.**

(**Ans.** 43.3 kW)

Solution: Area of indicated diagram $(a_d) = 0.075 \times 0.05\ m^2 = 3.75 \times 10^{-3}\ m^2$

Spring constant (k) = 147 MPa/m

$$p_m = \frac{a_d}{l_d} \times k$$

$$= \frac{0.075 \times 0.05}{0.075} \times 147\ MPa$$

$$= 7.35\ MPa = 7.35 \times 10^3\ kPa$$

L = 0.20 m

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.15)^2}{4} m^2 = 0.01767\ m^2$$

$$N = 50\ rpm$$

No. of stroke per minute = 2N

$$Power = \frac{p_m LA(2N)}{60} = \frac{7.35 \times 10^3 \times 0.20 \times 0.01767 \times 2 \times 50}{60} kW$$

$$= 43.29\ kW$$

Q3.15 **If a gas of volume 6000 cm³ and at pressure of 100 kPa is compressed quasistatically according to pV^2 = constant until the volume becomes 2000 cm³, determine the final pressure and the work transfer.**

(**Ans.** 900 kPa, – 1.2 kJ)

Solution: Initial volume $(V_1) = 6000\ cm^3$

$= 0.006\ m^3$

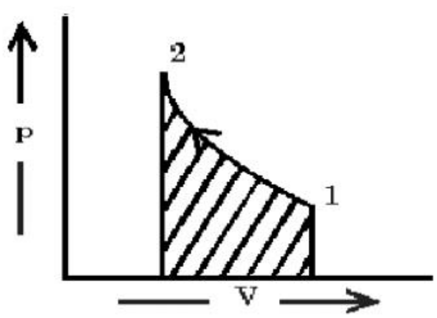
Initial pressure $(p_1) = 100\ kPa$

Final volume $(V_2) = 2000\ cm^3$

$= 0.002\ m^3$

If final pressure (p_2)

$$\therefore \quad p_2 = \frac{p_1 V_1^2}{V_2^2} = \frac{100 \times (0.006)^2}{(0.002)^2} = 900\ kPa$$



$$\text{work done on the system} = \frac{1}{n-1}[p_2V_2 - p_1V_1]$$

$$= \frac{1}{2-1}[900 \times 0.002 - 100 \times 0.006]\ kJ$$

$$= 1.2\ kJ$$

Q3.18 **680 kg of fish at 5°C are to be frozen and stored at – 12°C. The specific heat of fish above freezing point is 3.182, and below freezing point is 1.717 kJ/kg K. The freezing point is – 2°C, and the latent heat of fusion is 234.5 kJ/kg. How much heat must be removed to cool the fish, and what per cent of this is latent heat?**

(**Ans.** 186.28 MJ, 85.6%)

Solution: Heat to be removed above freezing point

= 680 × 3.182 × {5 – (-2)} kJ

= 15.146 MJ

Heat to be removed latent heat

= 680 × 234.5 kJ

= 159.460 MJ

Heat to be removed below freezing point

= 680 × 1.717 × {– 2 – (– 12)} kJ

= 11.676 MJ

∴ Total Heat = 186.2816 MJ

$$\% \text{ of Latent heat} = \frac{159.460}{186.2816} \times 100 = 85.6\ \%$$

THERMODYNAMICS PREVIOUS QUESTIONS UNIT WISE TO PRACTICE

UNIT-I

1.The following data refer to 12-cylinder, single-acting, two-stroke marine diesel engine: Speed= 150 rpm, Cylinder diameter = 0.8 m, Stroke of piston = 1.2 m; Area of indicator diagram = 5.5 x 10^{-4} $m^{2,}$ Length of diagram=0.06m,Spring value=147 Mpa/m. Find the net rate of work transfer from the gas to the pistons in kW. **2015-S**

2.A cooling tower nozzle disperses water into a stream of droplets. If the average diameter of the droplets is 60 microns, estimate the work required for atomizing 1 kg of water isothermally at the ambient conditions. Given; surface tension of water in contact with air = 0.07 N/m, density of water = 1000 kg/m^3. Water is assumed to enter the nozzle through a pipe of 15 mm diameter. **2015-S**

3.An electric motor drives a stirrer fitted with a horizontal cylinder. The cylinder of 40 cm diameter contains a fluid restrained by a frictionless piston. During the stirring of fluid for 15 min the piston moves outward slowly by a distance of 30 cm against the atmospheric pressure of 1 bar. The current supplied to the motor is 0.5 amp. From a 24-V lead-acid accumulator. If the conversion efficiency from electrical work to mechanical work output is 90%, estimate the work done on the motor, stirrer and the atmosphere. **2015-S**

4.A piston cylinder device with air at an initial temperature of 30°C undergoes an expansion process for which pressure and volume are related as below: Calculate the work done by the system. (8M+8M) **2015-S**

p (kPa)	100	37.9	14.4
V (m^3)	0.1	0.2	0.4

5. It is required to melt 5 tonnes/h of iron from a charge at 15°C to molten metal at 1650°C.The melting point is 1535°C, and the latent heat is 270 kJ/kg. The specific heat in solid state is 0.502 and in liquid state (29.93/atomic weight) kJ/kg K. If an electric furnace has 70% efficiency, find the kW rating needed. If the density in molten state is 6900 kg/m^3 and the bath volume is three times the hourly melting rate, find the dimensions of the cylindrical furnace if the length to diameter ratio is 2. The atomic weight of iron is 56. (8M+8M) **2015-S**

6.A new scale N of temperature is divided in such a way that the freezing point ice is 100^0N and the boiling point is 400^0N. what is the temperature reading on this new scale when the temperature is 150^0C,160^0C and 200^0C. Also determine at what temperature both the Celsius scale and the new temperature scale reading would be the same. **2015-RD,2016-R**

7. 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 work done when the volume changes from 3 m^3 to 6 m^3. **2015-RD**

8.A gas in a piston cylinder assembly undergoes an expansion process for which the relationship between pressure and volume is given by PV^n= constant. The initial pressure is 0.3 MPa, the initial volume is 0.1 m^3 and the final volume is 0.2 m^3 Determine the work done by the process in kJ if n= 1.5. **2015-RD**

9..A mass of gas is compressed in a quasi-static process from 80 kPa, 0.1 m^3 to 0.4 MPa, 0.03 m^3. Assuming that the pressures volume are related by PV^n=constant, find net work done by gas system.**2017-S**

10. A gas in a piston cylinder assembly undergoes an expansion process for which the relationship between pressure and volume is given by PV^n= const. The initial pressure is 0.3 MPa, the initial volume is 0.1 m^3 and the final volume is 0.2 m^3. Determine the work for the process in kJ if i) n = 1.5, ii) n=1.0 and iii) n=0. **2016-R**

11. A milk chilling unit can remove heat from the milk at a rate of 41.87 MJ/H. Heat leaking into milk from surroundings at an average rate of 4.187 MJ/h. Find the time required for cooling a batch of 500 kg of milk from 45^0C to 5^0C. Take the Cp of milk to be 4.187 kJ/kg K. **2016-R**