THERMODYNAMICS

Introduction

Thermodynamics is complex world i.e.
Thermo → "Heat" and Dynamics "Motion".
So, by their words we can say that the "motion of heat from one body to another body" is called Thermodynamics.

The study of the relations between heat, work, temperature and study. The father of thermodynamics "Nicolas Leonard Sadi Carnot".

The branch of mechanical engineering in which we deals with relation between heat and other form of energy, radiation and physical properties of matter.
The branch of

It is actually "Heat force interaction between matter"

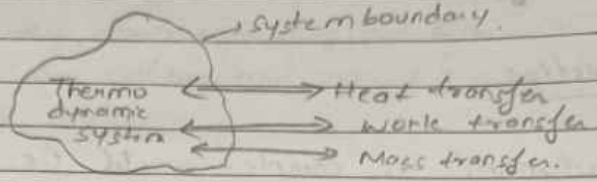
Thermodynamics System

The system is any prescribed and any indifferentiable collection of matter whose behaviour is being investigated. The system has a constant mass of matter.

Boundary: The quantity of matter or region of space must be within a prescribed of boundary. The boundary may be deformable or rigid.

i) Diathermic : Heat conduction allowed but no gas transfer.
ii) Adiabatic : No transfer of heat or gas.

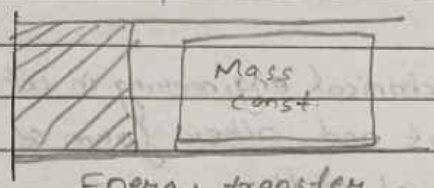
Surrounding: Everything, external to system is called surrounding.



Possible interaction with surrounding.

Fig. 1.1. System, boundary and surrounding.

Closed system: Any system in which mass does not cross the system boundary but energy may cross the system boundary. Closed system are also known as control mass.

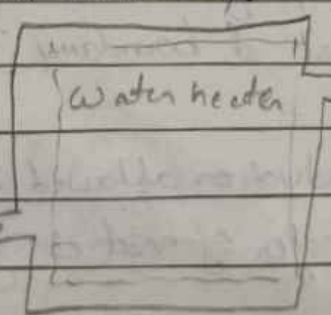


closed system.

E.g.: i) Kitchen refrigerator: Electricity is supplied to compressor motor and heat is lost to atmosphere

ii) Pressure Cooker: According to definition, a sealed pressure cooker with the whistle in position is a closed system as no mass can enter or leave the pressure cooker, but heat can be transferred to it.

Open System: Any system in which both mass and energy may cross the system boundary.

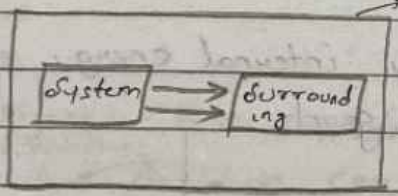


Examples of open system: Pumps

The stovetop: Heat and water vapour can be lost to the air
With pumps, compressors, aircraft engines or gas turbines,
In these system, mass enter the system from one side and
leaves on the other.

* If the rate of mass and energy transfer with time is constant
That type of system is called steady flow system.

Isolated System: A system there is no exchange of mass
and energy.



The thermos or cooler is approx an isolated system.

Thermodynamic properties: Any observable and measurable
characteristics of substance.
Volume, pressure and temperature are the properties.
These properties are also called internal or thermostatic
properties as these are dependent on the physical and
chemical structure of substance.

Types of properties:

1. Intensive: Independent of system mass. Ex: Pressure, temperature,
density, velocity. They are not additive, can be easily
identify.

Surface tension,

Extensive: Depends on system mass. They are additive.
Ex: Entropy, heat, volume, internal energy, enthalpy, heat capacity, gibbs energy, enthalpy etc., can't be easily identify.

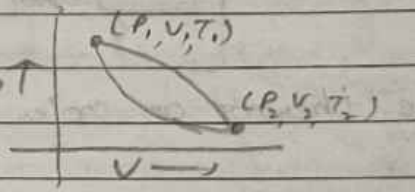
* Intensive can be created by using specific.

*

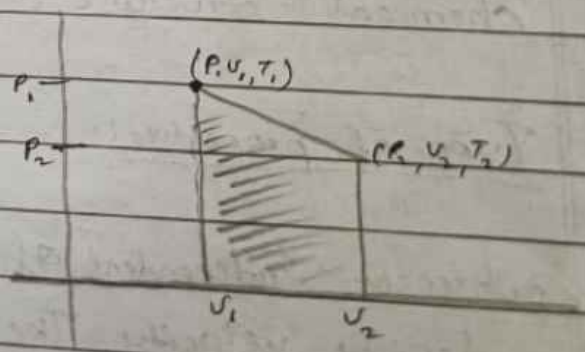
☆ Adiabatic system: A system which is thermally insulated from its surrounding called adiabatic. It can exchange work with surrounding.
Ex:

Point functions: Whose value doesn't depend on the path taken to reach the specific value called state function or point function.
Ex: Density, enthalpy, internal energy, entropy etc.

* It can be plotted on graph.



Path functions: A certain quantity can't be located or plotted at point by a point but are given by the area under the curve corresponding to the process.
Such properties are called Path function.
Ex: Heat and work.



Non flow and ~~non~~ flow processes:
The processes undergone by the fluid in a closed system are described as non-flow processes.

Those undergone by fluid in an open system are reffered as flow processes.

If at every point in the cycle the system is in thermodynamic ~~system~~ equilibrium, the cycle is reversible.
Whether carried out reversible or irreversibly, the net entrophy change of system is 0. as entrophy is a state function.

Reversible Process: A process involving a system and its surrounding, whose direction can be reversed by infinitesimal change in some properties of surrounding such as pressure or temperature.

To maintain equilibrium, reversible process are extremely ~~sol~~ slow (quasistatic).
Ex: Melting & freezing of ice in water

- Dimension: A physical variable used to specify the behaviour or nature of particular system. Ex: length, mass

Unit: Used to measure dimension. Ex: (mm), m, kg, g.

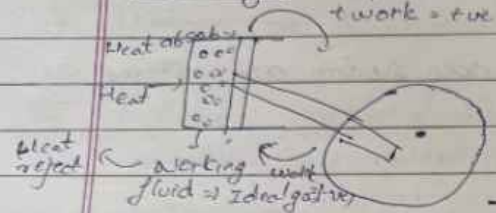
Dimension: Types of fundamental unit & basic unit & Secondary & supplementary unit.
Basic: Unit for characterizing fundamental dimension.
SI: SI system of units is an abbreviation for system International d'Unités, adopted by General Conference of wt. & measure in 1960.
It is coherent system.

In coherent system all derived unit quantities are formed by the product or quotient of other unit quantities.

Phase: A quantity of matter, homogeneous in chemical composition and physical structure called phase.

Carnot's Heat Engine

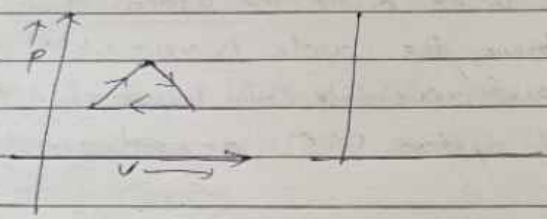
Heat Engine: Any such engine which convert heat into work.



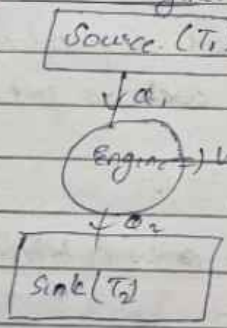
Net work = (+ve)

1 complete cycle ⇒ 1-stroke.

→ All heat can not be converted to work



★ Heat Engine: Convert Heat ⇒ Work done.



$T_1 > T_2$

$Q_1 = W + Q_2$

$$\text{efficiency } \eta = \frac{\text{Work done}}{\text{Heat absorb}}$$

$$\eta = \frac{W}{Q} \times 100\%$$

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

Carnot's Heat Engine:

⇒ Most efficient engine.

⇒ Hypothetical engine.

⇒ Reversible Engine

⇒ η = Max^m of any such engine which works blw same two temp T_1 & T_2

Source (T_1)

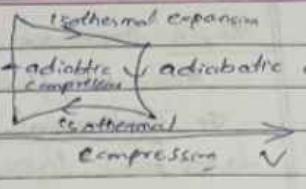
Q_1

Engine

Q_2

Sink (T_2)

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

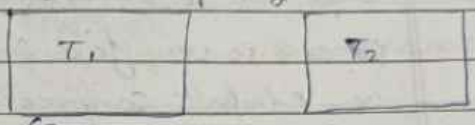


Compression, $W = -ve$

Expansion, $W = +ve$.

Carnot's Heat Engine

C = Heat capacity



Step 1:

Removal of slowly weight

gases expan

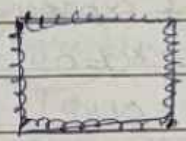
Work done by their internal energy as its temperature decreases

Isothermal Expansion.

Temp = const

Gas expand.

Source.

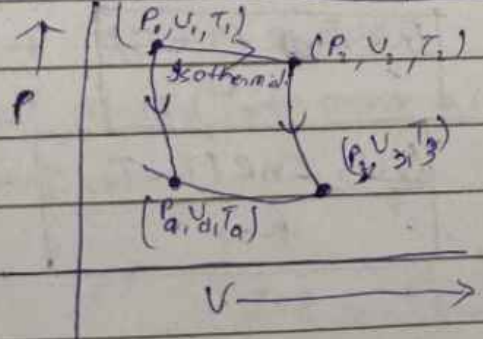


Step 2:

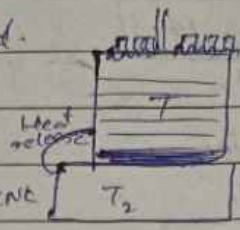
STAND: perfectly insulating

Adiabatic

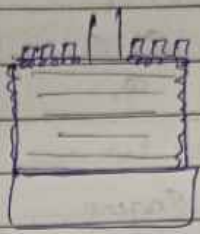
- Very fast and perfectly insulating
- Work is done by their internal energy. Expansion takes place until Temp raises upto T_2.

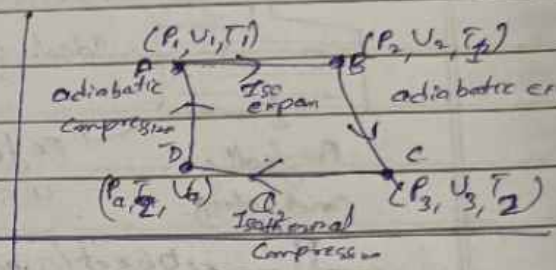


Step 3: ~~Expansion~~ slowly put out. Base → Perfectly conducting. ∴ Isothermal compression takes place. Work is done on the system. Heat released.



Step 4: Inside heat form but stand is perfectly insulating and heat won't released and process is very fast. So, it is Adiabatic Compression.





In AB:

Isothermal expansion:

$\Delta T = 0 \Rightarrow \Delta U = 0$

$Q = W + \Delta U$

$\boxed{Q = W}$

$\boxed{W_1 = nRT \ln\left(\frac{V_2}{V_1}\right)}$ — (I)

In BC: adiabatic expansion

$Q = 0$

~~$W = Q$~~ $Q = W + \Delta U$

$\boxed{W_2 = -U}$

$\boxed{W_2 = \frac{nR(T_2 - T_1)}{1-\gamma}}$

$\boxed{U_2 = \frac{nR(T_1 - T_2)}{1-\gamma}}$ — (II)

In CD: Isothermal compression

$\Delta T = 0 \Rightarrow \Delta U = 0$.

$Q = W$

$\boxed{Q_3 = W_3 = nRT_2 \ln\left(\frac{V_4}{V_3}\right)}$ — (IV)

In DA: Adobatic compression:

$Q = 0$

$\boxed{W_4 = \frac{nR(T_1 - T_2)}{1-\gamma}}$

$\boxed{\Delta U_2 = -\frac{nR(T_1 - T_2)}{1-\gamma}}$ — (III)

By adding (I) to (IV), we get

$\boxed{W = 0}$

$\eta = \frac{W_{net}}{Q_1} = \frac{W_1 + W_2 + W_3 + W_4}{Q_1}$

$\eta = \frac{W_1 + W_3}{nRT_1 \ln}$

$\eta = nRT_1 \ln\left(\frac{U_2}{U_1}\right) + nRT_2 \ln\left(\frac{U_4}{U_3}\right)$

$= nR\left(T_1 \ln\left(\frac{U_2}{U_1}\right) + \ln\left(\frac{U_4}{U_3}\right) T_2\right)$

$\eta = \frac{nRT_1 \ln\left(\frac{U_2}{U_1}\right) + nRT_2 \ln\left(\frac{U_4}{U_3}\right)}{nRT_1 \ln\left(\frac{U_2}{U_1}\right)} = 1 + \frac{T_2 \ln\left(\frac{U_4}{U_3}\right)}{T_1 \ln\left(\frac{U_2}{U_1}\right)} = 1 - \frac{T_2}{T_1}$ Ans proved

In Isothermal.

$P_1 U_1 = P_2 U_2$

In adiabatic: $P_2 U_2^{\gamma} = P_3 U_3^{\gamma}$

In Isothermal: $P_3 U_3 = U_4 P_4$

In adiabatic: $P_4 U_4^{\gamma} = P_1 U_1^{\gamma}$

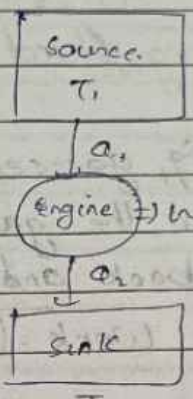
For multiply eq(i), (ii), (iii) & (iv)

$U_1 U_2^{\gamma} U_3 U_4^{\gamma} = U_2 U_3^{\gamma} U_4 U_1^{\gamma}$

$U_2^{\gamma-1} U_1^{1-\gamma} U_3^{1-\gamma} U_4^{\gamma-1} = 1$

$U_2 U_4 = U_3 U_1$

$\boxed{\frac{U_2}{U_1} = \frac{U_3}{U_4}}$



$W = Q_1 - Q_2$

$\boxed{\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}}$

$\boxed{\frac{Q_2}{Q_1} = \frac{T_2}{T_1}}$

Source = 227°C = 500k

Sink = 127°C = 400k.

Heat absobed from source = 10^4 J.

Work done: $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

$\boxed{Q_2 = \frac{4 \times 10^4}{5} = \frac{40^8 \times 10^3}{5} = 8000}$

$\frac{400}{500} = \frac{Q_2}{10^4}$

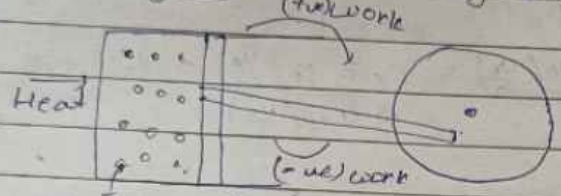
$W = Q_1 - Q_2$

$= 10000 - 8000$

$= 2000$ J.

→ Carnot's Heat Engine
→ Working, Graph.
→ Derivation of $\eta = 1 - \frac{T_2}{T_1}$ in depth Explanation
→ Refrigerator
→ Numerical

Heat Engine: Any such engine which convert heat to work.

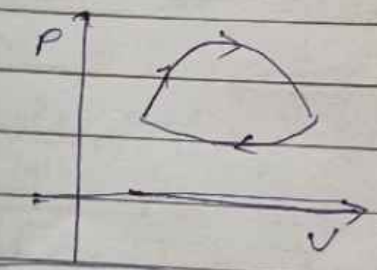


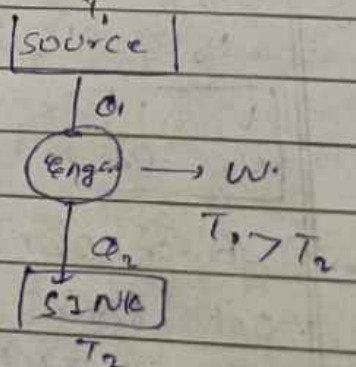
working fluid → Ideal.

On Heating, gases expland, the piston move forward and tyre move, now the gas stop expanding, and then, due to interia it moves back and (-ve) work done. → 1 stroke of Engine.

Net work = (+ve)

All heat can not be converted to work.





$$\text{Efficiency} = \frac{\text{work done}}{\text{Heat absorbed}} \times 100\%$$

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

$$Q_2 = W + Q_2$$

$$Q_1 - Q_2 = W$$

Carnot's Heat Engine

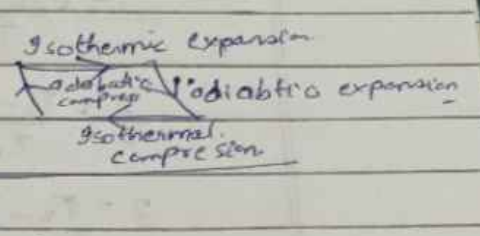
"Most Efficient engine"

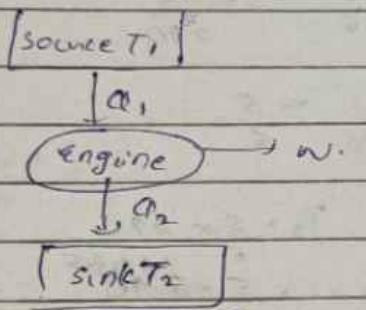
→ It is an hypothetical Engine.

→ Reversible process in this engine.

η = Max^m of any such engine which works between same temp. T_1 & T_2.

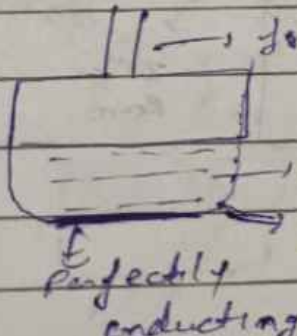
$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

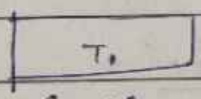




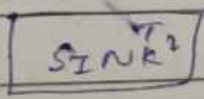
$$\eta = \frac{W}{Q} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Hypothetical set up:





Source perfectly conducting. It has (c/y) heat capacity.



Perfectly conducting.

2) $\eta = \frac{1}{6}$ if it is reduced by 65°C, $\eta = \frac{1}{3}$. Calculate actual sink temp.

$\eta = \frac{1}{6}$

$1 - \frac{T_2}{T_1} = \frac{1}{6}$

$1 - \frac{(T_2 - 65)}{T_1} = \frac{1}{3}$

$\frac{2}{3} = \frac{T_2 - 65}{T_1}$

$\frac{2}{3} = \frac{T_2}{T_1} - \frac{65}{T_1}$

$\frac{2}{3} = \frac{5}{6} - \frac{65}{T_1}$

$\frac{65}{T_1} = \frac{5}{6} - \frac{2}{3} = \frac{5-4}{6} = \frac{1}{6}$

$T_1 = 65 \times 6 = 390\text{K}$ | 117°C.

$T_2 = 390 - 65$

$\frac{1}{6} = 1 - \frac{T_2}{T_1}$

$\frac{1}{6} = 1 - \frac{T_2}{390}$

$\frac{T_2}{390} = \frac{5}{6}$

$T_2 = \frac{5}{6} \times 390$

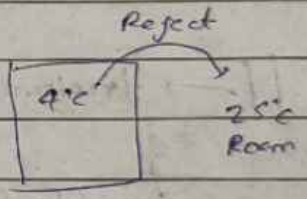
$= \frac{5}{6} \times 390 = 65$

$T_2 = 65 \times 5 = 325\text{K}$

390 / 2 / 195 / 65 / 5 / 325

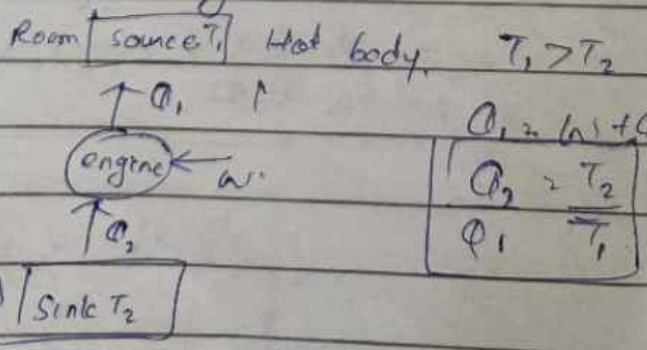
65 / 5 / 325

Refrigerator:



With help of Electric energy (work) ⇒ extract heat from cold body to hot body

If is reverse heat engine.



Inside refrigerator
$-3°C$

Room temp.
$27°C = 300K$

Q. How much heat is rejected to room per second if 15 of Electrical energy is given to refrigenerator per second.

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

$$\frac{Q_2}{Q_1} = \frac{270}{300} = \frac{9}{10}$$

$$\frac{Q_1}{Q_2} = \frac{10}{9}$$

$$\frac{Q_1 - Q_2}{Q_1} = \frac{10-9}{9} = \frac{1}{9}$$

$$\frac{15}{Q_1} = \frac{1}{9}$$

$$\boxed{Q_1 = 135\,J}$$

Coefficient of performance:

K = heat rejected ↑ / Work done ↓

$$\boxed{K = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}}$$

Extensive

Specific/Molar → convert into intensive.

point fun° | **State function**: Variables like P, V, T are called state variables or state functions because their values depend only on the state of system and not on how it is reached.
Ex: U, G, H, S etc. It can be plotted on graph.

Path functions: Those physical quantities which depends on the path followed called path function.
E.g. Work, heat etc. It can't be located on graph.

Extensive ± Intensive = Extensive

Thermodynamic Process:

i) Isothermal Process ⇒ $\Delta U = 0 \Rightarrow T = \text{const.}$

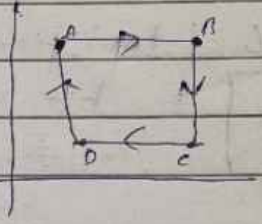
ii) Isobaric Process ⇒ $P = \text{Const.} \Rightarrow \Delta P = 0$.

iii) Isochoric Process ⇒ $V = 0 \Rightarrow W_{\text{by/on}} = 0$.

iv) Adiabatic Process ⇒ $Q = 0 \Rightarrow W = -\Delta U$

Cyclic process

Initial and final state remain same.

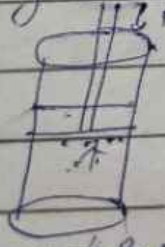


change state function = 0

Reversible and Irreversible process:

Slow ‖ Fast

takes Infinite time ‖ takes finite time.



$P_{ext} = P_{in} + \Delta P$

$P_{ext} \neq P_{in}$

$P_{ext} = \text{Const}$

$P_{ext} \neq P_{in}$.

Internal Energy: It is sum of all different types of energies associated with all the particles present in the system. It is absolute value cannot be determined but experimentally change in internal energy (Δ) can be determined.

A change in internal energy may be brought about when:
- Heat passes into or out of the system
- Work is done on or by the system.
- Matter enters or leave the system.

→ State function

$\Delta T = 0 \Rightarrow \Delta U = 0$

$U = nC_v(\Delta T)$

First Law of Thermodynamics:

$\Delta U = q + W$.

$q = +ve \Rightarrow$ (Heat absorbed)

$q = -ve \Rightarrow$ (Heat released)

$W = -ve \Rightarrow$ (By the system)

$W = +ve \Rightarrow$ (On the system)

Heat Capacity or thermal capacity is a physical property of matter defined as the amount of heat to be supplied to an object to produce a unit change in its temperature. $\boxed{C = \frac{q}{\Delta T}}$

Specific heat Capacity: The quantity of heat (q) absorbed per unit mass (kg) of the material when its temperature increases 1K (or 1°C) $\boxed{q = mS\Delta T}$

Molar heat capacity: The molar heat capacity is the amount of energy required to raise the temperature of one mole of substance by 1°C $\boxed{q = mC_m\Delta T}$

$C_p - C_v = R$

Isochoric process: Volume = const. $\Rightarrow dV = 0$

$W = -\int P_{ext} \cdot dV = 0$

Isobaric process: P = const

$W_2 = -\int P_{ext} \cdot dV$

$= -P_{ext}(V_2 - V_1)$

Isothermal Process:

$W_{reversible} = -2.303 nRT \log_{10}\left(\frac{V_2}{V_1}\right)$

$W_{irreversible} = -P_{ext}(V_2 - V_1)$

* **Expansion:**

$|W_{rev}| > |W_{irreversible}|$

* **Compression:**

$|W_{irreversible}| > W_{reversible}$

Adiabatic Process:

$q = 0$

$U = q + W$

$W_{rev} = n C_v (T_2 - T_1)$

$C_v = \frac{R}{\gamma - 1}$

Possion ratio, $\gamma = \frac{C_p}{C_v}$

The ratio of ~~two~~ transverse contraction strain to longitudal extension strain in the direction of stretching force

$W = \frac{nR}{\gamma - 1}(T_2 - T_1)$

Adiabatic reversible process:

$PV^{\gamma} = K$

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

$P^{1-\gamma}T^{\gamma} = K$

Free Expansion

Expansion of gas in vaccum.

$P_{ext} = 0$.

$W = -\int P_{ext} \cdot dV$

$\boxed{W = 0}$

Enthalphy, H:

- $\Delta H = q_p \Rightarrow$ Heat absorbed or released by system at constant pressure is called ΔH.

$\boxed{q_p = nC_p\Delta T}$

$PCl_5(g) \longrightarrow PCl_3 + Cl_2(g)$ $n_g = 2-1 = 1$.

$N_2 + 3H_2 \longrightarrow 2NH_3$ $n_g = (2-4) = -2$

$\boxed{\Delta H = \Delta U + P(\Delta V)}$

$\boxed{\Delta H = \Delta U + \Delta n_g RT}$

Calorimetry: Practical measurement of heat change in chemical and physical change is known as calorimetry.

Bomb calorimeter: Used to calculate the value of ΔU.

$\Delta T = T_2 - T_1$

$q_{comb} = -C(\Delta T)$ ← Heat capacity

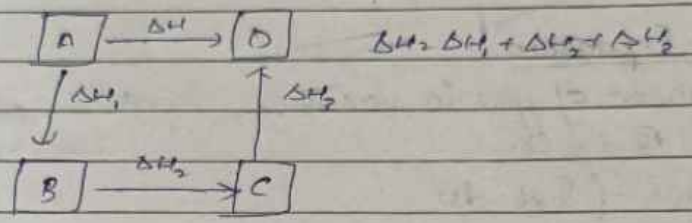
$\Delta U = -C(\Delta T)$

Enthalpy of Reaction: The enthalpy change accompanying a reaction is called a reaction enthalpy.

$A \rightarrow B$. $\quad \Delta_r H = H_B - H_A$.

$$\Delta_r H = \Sigma n_i (H)_{product} - \Sigma q_i (H)_{reactants}$$

Hess's Law:



$\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3$

Standard Enthalpy of Reaction: The standard enthalpy of reaction is enthalpy change for a reaction when all the participating substance are in their standard states. ($\Delta_r H^\circ$)

Enthalpy of Reaction:

Molar Enthalpy of Fusion: The enthalpy change that accompanies melting of one mole of solid substance in standard state

$H_2O(s) \longrightarrow H_2O(l)$ $\quad \Delta_{fus} H^\circ = \Delta_r H^\circ (0,s)$

Molar enthalpy of vapourisation: ($\Delta_{vap} H^\circ$) : Amount of heat required to vapourize one mole of a liquid at const. temp and under standard pressure (1 bar).

$H_2O(l) \longrightarrow H_2O(g)$

$\Delta_r H^\circ = \Delta_{vap} H^\circ (H_2O, l)$.

Molar enthalpy of sublimation: $\Delta_{sub} H^\circ$ is change in enthalpy when one mole of solid substance sublimises at a constant temp. and under standard pressure (1 bar).

$I_2(s) \longrightarrow I_2(g)$ $\quad \Delta_r H^\circ = \Delta_{sub} H^\circ$

Standard enthalpy of formation: The standard enthalpy change for the formation of one mole of compound from its elements in their most stable state of aggregation.

$\frac{1}{2}O_2(g) + H_2(g) \longrightarrow H_2O(l)$ $\quad \Delta_f H^\circ = \Delta_f H^\circ(H_2O)$

$C(\text{graphite}) + O_2(g) \longrightarrow CO_2(g)$ $\quad \Delta_r H^\circ = \Delta_f H^\circ(CO_2)$

$$\Delta_r H^\circ = \Sigma a_i \Delta_f H^\circ(\text{products}) - \Sigma a_i \Delta_f H^\circ(\text{reactants})$$

Standard Enthalpy of Atomization: It may be defined as the enthalpy change during the conversion of 1 mol of molecule or element into gaseous atoms.

$H_2(g) \longrightarrow 2H(g)$ $\quad \Delta_a H^\circ = \Delta_a H^\circ(H_2, g)$

$CH_4(g) \longrightarrow C(g) + 4H(g)$ $\quad \Delta_a H^\circ = \Delta_a H^\circ(CH_4, g)$

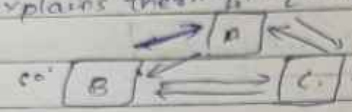
$Na(s) \longrightarrow Na(g)$, $\quad \Delta_a H^\circ = \Delta_a H^\circ(Na, s)$

Bond Enthalpy: It may be defined as the amount of energy required to break one mole of bond of particular type between two atom in the gaseous phase.

$$\Delta_r H^\circ = \Sigma a_i \Delta_{bond} H(\text{Reactant}) - \Sigma a_i \Delta_f H(\text{product})$$

2nd Laws of thermodynamics:

Zeroth law: If bodies B and C are in thermal equilibrium with body A, the body B and C are also under thermal equilibrium with each other.
It explains thermal equilibrium.



~~1st law: Every Energy Energy neither be created nor be destroyed but~~

First Law: Energy neither be created nor be destroyed, but it can change its form from one to another.

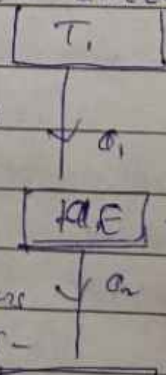
$$W = Q$$

It provide the mechanical work-heat interaction.
In an isolated system the sum of all forms of energy is constant.
An equivalent statement is that Perpetual motion machine of the first kind are impossible,

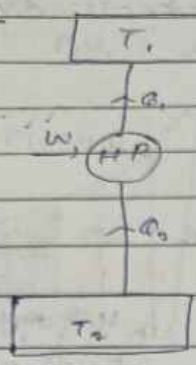
Second Law: It explains the directions of flow of heat.

Kelvin Plank

If a heat engine want to produce the work then it has to exchange it's heat exchange with two reservoirs which are present at different temperature T_1 & T_2



Clausius



"Heat can flow from lower temp. to higher temp but for that some external work must be supplied".

Kelvin-Planck statement

"It is impossible for any device that operate in a cycle to receive heat from single reservoir and produce a net amount of work".

Clausius statement: It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from lower temp. body to higher temp. body.

Non-flow Process: Mass = const.

A process undergone by closed system of fixed mass is called non-flow process. This process doesn't permit the flow of mass in or out of system.

Flow process: In this process, the fluid enters the system and leave after doing work.

→ This implies open boundary which permit the flow of the mass to and from the system.

Flow process and control volume:

→ A flow process constitutes an open system through which the working fluid enters and leave from the surface of system.

→ They may also be energy interaction in the form of heat and work, internal energy, KE, PE etc.

→ Most of engineering device such as internal combustion engine, steam engine, boilers, turbines, pumps, compressors, condensers etc.

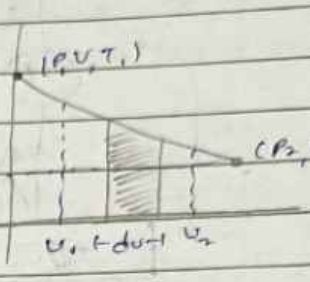
→ The working fluid continuously flow in and out of plant of devices.

Analysis of flow process in such device is done with concept of control volume or control surface.

Hyperbolic Expansion: $PV = const.$

Isothermal

Work done during a small change in volume = Area of shaded strip = PdV



$$W = \int_{V_1}^{V_2} P \cdot dV = P(V_2 - V_1)$$

$T = const \Rightarrow U = 0$. $PV = nRT$.

$\Delta Q = U + W$.

$\Delta Q = W$

$$PV = P_1V_1$$

$$P = \frac{P_1V_1}{V}$$

$$\boxed{\Delta Q = P_1V_1 \log\left(\frac{V_2}{V_1}\right)}$$

$$W = \int_{V_1}^{V_2} P\,dV$$

$$\boxed{\Delta Q = nRT \log\left(\frac{V_2}{V_1}\right)}$$

$$= \int_{V_1}^{V_2} \left(\frac{P_1V_1}{V}\right) dV.$$

This curve is represent by with expansion of PV^n in which $PV^n = const$

n is called index of expansion.

$n = 0 \Rightarrow$ Const pressure process.

$n = \infty \Rightarrow$ Const volume process.

$$P_1V_1 \int_{V_1}^{V_2} \frac{1}{V}\,dV = P_1V_1 [\log V]_{V_1}^{V_2}$$

$$= P_1V_1 [\log(V_2) - \log(V_1)]$$

$$W = P_1V_1 \log\left(\frac{V_2}{V_1}\right)$$

$$\boxed{W = P_1V_1 \log\left(\frac{V_2}{V_1}\right)}$$

PMM, Perpetual motion machine: Work done by a system on surrounding require that system's internal energy be consumed, so that the amount of internal energy lost by that work must be resupplied as heat by an external source or as work by an external machine acting on the system to sustain the work of system continuously.

$\frac{-n+1}{1-n}$

* Adiabatic

$PV^{\gamma} = P_1V_1^{\gamma} \quad P = \frac{P_1V_1^{\gamma}}{V^{\gamma}}$

$W = \int P \cdot dV$

$= \int \frac{P_1V_1^{\gamma}}{V^{\gamma}} dV$

$= P_1V_1^{\gamma} \int \frac{1}{V^{\gamma}} dV$

$= P_1V_1^{\gamma} \left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_1}^{V_2}$

$= P_1V_1^{\gamma} \left[\frac{V^{1-\gamma}}{1-\gamma}\right]_{V_1}^{V_2}$

$= \frac{P_1V_1^{\gamma}}{1-\gamma} \left[V^{1-\gamma}\right]_{V_1}^{V_2}$

$= \frac{P_1V_1^{\gamma}}{1-\gamma} \left[(V_2)^{1-\gamma} - (V_1)^{1-\gamma}\right]$

$W_{adiabatic} = \frac{nR}{\gamma-1} [T_1 - T_2]$

It is one of which there is no heat is supplied or rejected. In this

$PV^{\gamma} = K$

$W = \int P \cdot dV$

$W = \int \frac{K}{V^{\gamma}} dV$

$= \int K V^{-\gamma} dV$

$= K \left[\frac{V^{1-\gamma}}{1-\gamma}\right]_{V_1}^{V_2} = \frac{K}{1-\gamma} \left[V_2^{(1-\gamma)} - (V_1)^{1-\gamma}\right]$

$= \frac{K}{1-\gamma} \left[V_2^{(1-\gamma)} - (V_1)^{(1-\gamma)}\right]$

$= \frac{K^{\gamma}}{1-\gamma} \left[V_2^{(1-\gamma)} - V_1^{(1-\gamma)}\right]$ $\quad \gamma+1-\gamma$

$= \frac{P}{1-\gamma} \left[P_1V_2^{\gamma}V^{1-\gamma} - P_1V_1^{\gamma}V_1^{1-\gamma}\right]$

$W = \frac{1}{1-\gamma} \left[P_2V_2 - P_1V_1\right]$ $\quad \boxed{\frac{P_2V_2 - P_1V_1}{\gamma-1} = W}$

$Q = U + W$

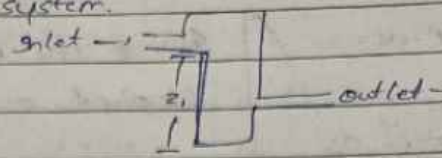
$\frac{C_v}{R}(PdV + VdP) + PdV = 0$

$\frac{PdV + VdP}{\gamma-1} + PdV = 0$

$\boxed{\ln P + \gamma \ln V = C_1}$

C_2 cant. of integration. It will be seen there exist a property which remain cont. during an adiabatic reversible change of stat. Therefore such a process is called Isothem process

Steady flow process: In steady flow process, the mass flow is same at inlet and outlet and properties of fluid don't change with time at any point in the system.



Assume the unit mass of fluid and this control volume at 1.

Let initial ~~pressure~~ be P_1,

Initially, P_1, V_1, C_1 and U_1 are respective properties which means Pressure, volume, speed and internal energy at ht. h. above a certain level.

Finally, P_2, U_2, C_2 and U_2 are respective properties which means final Pressure, ~~tem~~ volume speed and Internal energy.

Energy	Initial	Final
Internal Energy	U_1	U_2
Kinetic Energy	$\frac{C_1^2}{2}$	$\frac{C_2^2}{2}$
potential Energy	gz_1	gz_2
Flow & displacement work	P_1V_1	P_2V_2

Let q be transfer ~~from~~ for a particular volume U and Work transfer W. It is assumed that energy contained with original boundary doesn't change

$$q + U_1 + P_1V_1 + \frac{C_1^2}{2} + z_1g = W + U_2 + P_2V_2 + \frac{C_2^2}{2} + z_2g.$$

$$q - W + U_1 - U_2 + P_1V_1 - P_2V_2 + \frac{C_1^2}{2} - \frac{C_2^2}{2} + z_1g - z_2g = 0.$$

$$(q - W) + (U_1 - U_2) + (P_1V_1 - P_2V_2) + \frac{1}{2}(C_1^2 - C_2^2) + g(z_1 - z_2) = 0.$$

$$\boxed{q - W + (U_1 - U_2) + (P_1V_1 - P_2V_2) + \frac{1}{2}(C_1^2 - C_2^2) + g(z_1 - z_2) = 0}$$

Steady flow energy equation.

Steady flow energy equation in differentiable form:

$$\boxed{\delta q - \delta w = dh + c\,dc + g\,dz}$$

If effect of gravity is neglected,
$z_1 = z_2$ which is common in thermodynamics.

By equation, reduced to: $q - w = (h_2 - h_1) + \left(\frac{c_2^2}{2} - \frac{c_1^2}{2}\right) \quad (z_1 = z_2)$

$(q - w) = (h_2 - h_1) \quad KE = 0.$

The condition used for summarisa steady flow and energy equation as follows:

1) The composition, state and velocity of stream crossing the control volume don't change with at entrance and exist.
2) The state of fluid at any point with in the control volume at same all times.
3) The mass rate of flow into control volume is const. and equal to the mass rate of flow out of it.
4) The rate at which heat and work cross the boundary is const.

Control volume: A fixed region in space chosen for the thermo dynamic study of mass and energy balance for flowing system. The boundary of control volume may be real or an imaginary envelope. The control surface is the boundary of control volume.

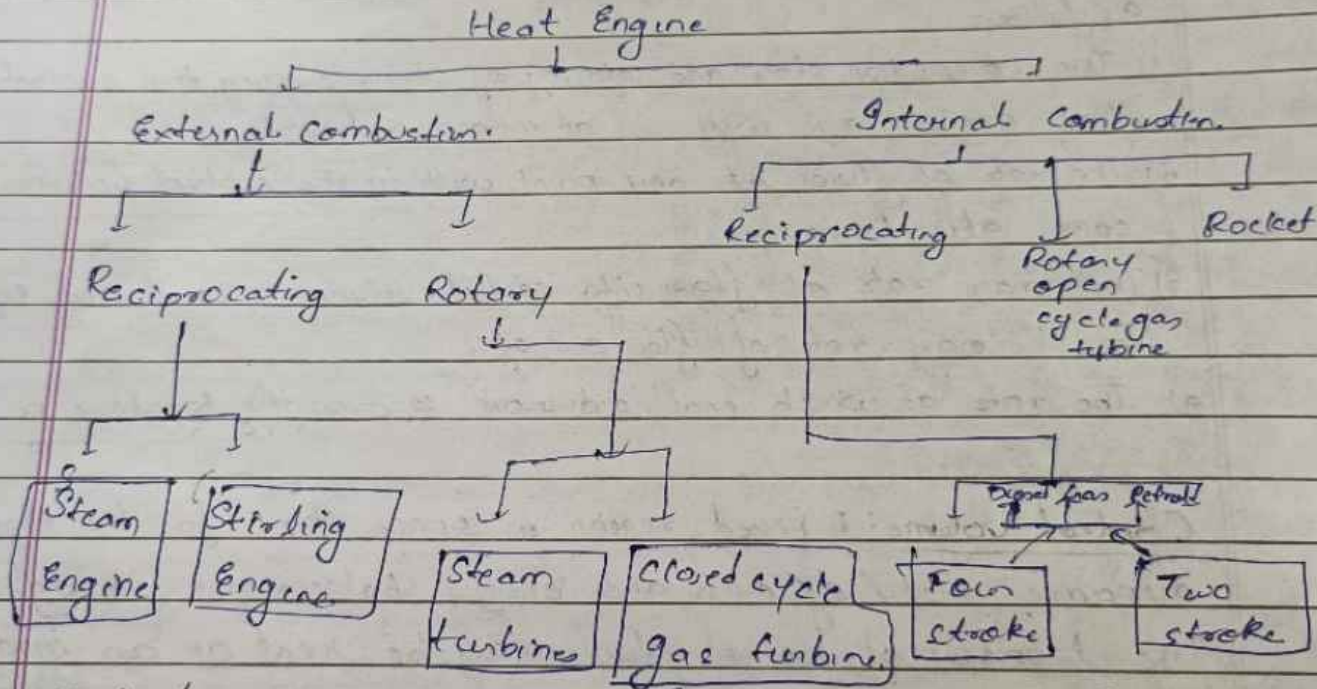
Steady flow equation:

$$m\left(h_1 + \frac{v_1^2}{2} + g z_1\right) + \frac{\Delta Q}{\Delta t} = m\left(h_2 + \frac{v_2^2}{2} + g z_2\right) + \frac{W}{t}$$

$Q - W = m[\Delta h + \Delta KE + \Delta P.E)$ $\quad H$ = enthalphy

$[h = U + PV]$

Applied thermodynamics:
The scope of subject is restricted to the study of relationship between heat and work and the properties of the working substance or the media employed to obtain the energy conversion.



→ A heat engine (steam engines & turbines, gas engines & turbines) working in a cyclic manner is work producing machine from supply of heat energy & where as compressors & refrigerator are work absorbing machines.

Microscopic & Macroscopic.

Microscopic	Macroscopic
i) Behaviour of individual atoms and molecules of substance are investigated & the behaviour of substance is predicted by averging.	i) Study about the gross characteristics of large aggregation of molecule.
ii) Used in statistical thermo and kinetic theorey of gases.	ii) Study the properties of particular mass of substance.
iii) Ex: Study of atomic structure in nuclear physics.	Ex: The measurement of pressure, volume and temperature.

Control volume:

Equilibrium: A body is said to be equilibrium if it doesn't tend to undergo any further change of its own accord. ~~Opposite~~ Opposing a state in which force are balanced. so that the body doesn't move.

i) Mechanical Equilibrium: There should not be any pressure unbalancing either in interior of system or between the system and surranding. A state where sum of all forces acting on an object of interest is 0.

ii) Chemical Equilibrium: Both reactant and products are present in concentration which have no further tendency to change with time, there is no observable change properties of system

iii) Thermal Equilibrium: a state in which two object are connected by permeable barrier don't have any heat transfer between them.

Date 0.48
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Numericals

Q. Given for a fluid:
$P_2 = 4$ bar
Vol. $= 0.16 m^3$.
Work done of fluid expand reversibly:
a) at const. pressure to a final volume of $0.69 m^3$.
b) ~~Work~~ $W = P(V_2 - V_1) = 4(0.69 - 0.16) = 0.48 \times 4 = \frac{48}{100} \times 4 = 0$

Thermodynamic equilibrium: If the system satisfies the condition of mechanical, chemical and thermal equilibrium, then, it is said to be in state of thermodynamic equilibrium.

Pure substance: A substance whose chemical composition is both homogeneous and const. are called pure substance.
Ex: steam or water. (they have the same molecular or chemical composition throughout its mass. It has only one type of atom or molecules thereby having a const. composition and structure.

Homogeneous: Substance exist in single phase. A homogeneous mixture is gaseous, liquid or solid mixture that same proportions of its component throughout a given sample.
Ex: Water, Air, steel, Detergent, saltwater mixture.
→ Uniform composition.

Heterogeneous mixture: A mixture in which the composition is not uniform throughout the mixture. Ex: Vegetable soup.

Pressure: Force per unit Area called Pressure.

1 atm = 1.01325 bar = 101325 Pa = 760 mm Hg.

1 bar = 10^5 N/m² = 100 kN/m²

Internal Energy: The energy due to the binding force of mutual attraction. Energy due to random motion of individual molecule and atoms and their vibration.

Internal energy depends on a change in temperature of system or change in its phase.

First law: For a system operating in a cycle the net work transfer is equal to net heat transfer.

For closed system: Energy is a property. There exist a propety of a system called energy such that a change in its value is equal to difference the heat supplied & work done during any change of state.

→ Non-flow energy equation: In case of closed system KE & PE are zero & energy is internal energy.

$$Q - W = U_2 - U_1$$

Flow of energy across the boundary occur as a result of movement of force at the boundary it termed as work.

If flow of energy across the boundary or cross as the result of difference blw the temp. of system & surrounding it is term as heat

Const. volum process (Isometric):

$C_v = \left[\frac{dU}{dT}\right]_v$ Isopiestic (Const. pressure process).

PMM-I: The continuous output of work from a system working in cycle with O input of energy is impossible.

→ It is hypothetical machine producing a continuous supply of work without absorbing energy from surrounding.
The First law implies that a perpetual motion machine of this kind is impossible, because if net amount of heat is not supplied by surrounding during cycle, no work done.

$Q = W + \Delta U = \int P.dV + (U_2 - U_1)$

$Q = W + \Delta U = \int P.dV + m C_v dT.$

Displacement work: The work is obtained by displacement of boundary is called displacement work. It takes place in non flow process.

Joule's Law: $(U_2 - U_1) = m C_v (T_2 - T_1)$ - (Internal energy change with fun^c of temp only).

Enthalphy: $H = U + PV.$

Specific heat at Cp: $\left(\frac{dh}{dT}\right)_p$: ratio of change in enthalphy to increase in temp.

$C_p - C_v = R$

$\gamma - 1 = \frac{R}{C_v}$

$\gamma = \frac{R}{C_v} + 1$

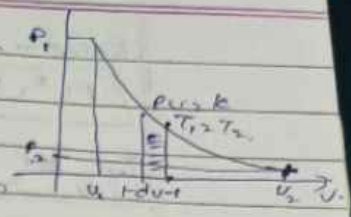
$\gamma = \frac{C_p}{C_v}$

* Hyperbolic expansion: $(PV = k)$ for whole expansion

→ Curve: rectangular hyperbola.

→ If expansion is called hyperbolic expansion.

for ideal gas, $\frac{PV}{T} = k \Rightarrow$ constant temp. expansion



$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \left(\frac{P_1V_1}{V}\right) dV = P_1V_1\left[\ln(V)\right]_{V_1}^{V_2} = P_1V_1\left[\ln(V_2) - \ln(V_1)\right]$$

$$= P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$PV = P_1V_1 = P_2V_2$

$P = \frac{P_1V_1}{V}$

$Q = W + (U_2 - U_1)$

$Q = P_1V_1 \ln\left(\frac{V_2}{V_1}\right) + 0$

$$\boxed{Q = mRT_1 \ln\left(\frac{V_2}{V_1}\right)} \qquad \boxed{Q = mRT_1 \ln\left(\frac{P_2}{P_1}\right)}$$

→ At const. temp i.e. $U = \text{const.} \Rightarrow \Delta U = 0$

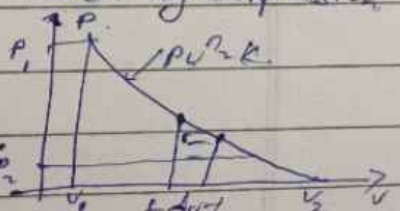
→ Slow process due to heat exchange at const. temp.

→ True reversible process as $T = \text{const.}$

→ Thus for compression the energy input in the form of work must immediately be dissipated without increase in internal energy.

* Polytropic Process $(PV^n = k)$

n = Index of expansion and for compression n = Index of compression



When $n = 0 \Rightarrow P = \text{const}$

$n = \infty \Rightarrow V = \text{const}$ $\qquad PV^n = P_1V_1^n = P_2V_2^n$

$$W = \int_{P_2}^{P_1} P \cdot dV = \int \frac{P_1V_1^n}{V^n} dV = \frac{P_1V_1^n}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{n-1}} \qquad W = \frac{mR(T_1 - T_2)}{(n-1)}$$

$$\boxed{Q = \frac{mR(T_2 - T_1)}{n-1} + mC_v(T_2 - T_1)} \rightarrow \text{for ideal gas.}$$

Relation b/w V & T:

$PV^n = K$

$TV^{n-1} = K$

$T_1(P_2)^{\frac{1-n}{n}} = K$

Adiabatic cond.

$\Delta Q = 0 \Rightarrow$ Work done $= \Delta U$

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

$C_p - C_v = R$

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

$PV^\gamma = K$

$\therefore$

1) $W = \frac{P_1V_1}{n-1}\left[1 - \frac{1}{2^{n-1}}\right]$

2) $H = \frac{\gamma - n}{\gamma - 1} \times W$

3) $\Delta H = \frac{\gamma(P_2V_2 - P_1V_1)}{\gamma - 1}$

Steady flow processes:

→ Mass of flow remain same at inlet & outlet

→ Properties of fluid don't change with time at any point on control volume.

Eq:

$q - W = (h_2 - h_1) + \left(\frac{c_2^2}{2} - \frac{c_1^2}{2}\right) + (z_2g - z_1g)$

$\delta q - \delta W = dh + c\,dc + g\,dz$

Conclusion: 1) composition, state & velocity of streams crossing control volume is same at all time.

2) State of fluid at any point within the control volume remain same.

3) Mass rate of flow into control volume is cont. & equal to mass rate of flow out of.

4) Rate at which Q & W cross the boundary is cont.