

Thermodynamics

- 1- Basic Concepts \rightarrow Objective
 - 2- 1st Law of TD
 - 3- 2nd Law of TD
 - 4- Entropy Concepts
 - 5- AE & UAF \rightarrow Obj
 - 6- Pure Substance \rightarrow Obj
 - 7- Mixture of Gases \rightarrow Obj
 - 8- TD Relation \rightarrow Obj
- Objective & Conventional Topic
- GATE ✓ ESE ✗

Wt. - GATE : 3-5 Marks
PSU : 7-8 Questions
ESE : 15-18 Q

Books : P.K. Nag
Cengel \rightarrow for Interview

~~Thermodynamics~~

Basic Concepts

Thermodynamics - It is the branch of science which deals with the study of energy interaction and its impact on the prop. of system.

OR

It is the branch of the science which deals with the study of three E (3 E'S) i.e., Energy, Equilibrium & Entropy.

OR

It is a branch of the science which deals with the conversion of disorganised form of energy into organised form.

System: Anything under consideration
OR

It is a control ~~are~~ region in space over which our attention is focused.

Surrounding: Everything external to the system.

Universe - System + Surrounding.

Boundary - Which separates system from surrounding.

→ Note: 1- Boundary may be real or imaginary. Real boundaries are represented by continuous line or curve, whereas imaginary boundaries are represented by dotted line or curves.

2- Boundary may be fixed (rigid, $dV=0$) or movable.

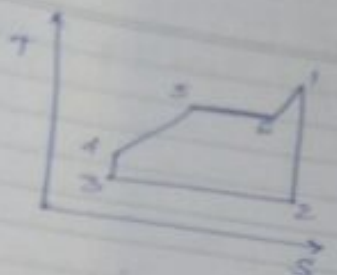
3- It should be considered of nearly zero thickness.

Types of Systems:

1- Open System - It is a system in which both mass as well as energy interaction takes place b/w system & surrounding. eg., boiler, turbine, condenser, evaporator, heat exchanger, pump, compressor, nozzle, diffuser, piston-cylinder arrangement with valve.

2- Closed system - In which only energy interaction takes place. eg., piston-cylinder arrangement without valve.

3- Isolated System - In which neither mass interaction nor energy interaction takes place. eg., Universe, thermoflask.



→ Turbine is an open system but its cycle represents it as a closed system. Open because energy at every pt. is different and mass (ie. water) flows in & out from inlet and moves out from outlet. Hence both mass flow and energy interaction is there. But if we consider whole system then mass of water in the system at every pt. or through out the process is same (Amount of water entered = Amount of water released). Hence it is a closed system on graph when whole cycle is considered as a system because mass in whole cycle is constant.

Microscopic vs Macroscopic -
Statistical Classical

In the case of microscopic approach individual particle is under consideration and this approach is also known as statistical approach whereas in the macroscopic approach time avg. behaviour of the molecule are under consideration and this approach is also known as classical approach.

→ Note : In our thermodynamics, we are generally dealing with macroscopic approach.

⑧ Continuum Approach -

In this approach the distance b/w the two molecules is neglected.

→ Note : In the case of Rarefied Gas Theory the concept of continuum is not valid.

→ Macroscopic Approach,
→ Rarefied Gas Theory

Thermodynamic Property-

It represents the characteristics of the system.

→ Types of property-

1- Intensive property or Intrinsic property-

These are independent of mass. eg, pressure, temp., all forms of specific energy (Energy/unit mass, i.e. energy per unit mass) like specific enthalpy, ratio of two extensive property like density, conductivity, coeff. of thermal expansion, specific heat, etc.

2- Extensive property or Extrinsic property-

These are dependent on mass. eg, Volume, mass, all forms of energy like kinetic energy, potential energy, internal energy, entropy, heat capacity (MC) etc.

Thermodynamic Equilibrium-

A system is said to be in thermodynamic eq^m if they are in thermal eq^m, mechanical eq^m and chemical eq^m.

Thermal eq^m means equality of temp., Mechanical eq^m means mechanical forces and pressure and chemical eq^m means equality of chemical reactions.

Exhaust gas has different types of gases i.e. having different conditions but still it is pure because it is a homogeneous mixture of all these different gases.

Pure Substance -

It is a substance of constant chemical composition throughout its volume of mixture irrespective of phase.

Eg. - H_2O $\left. \begin{array}{l} \text{ice} \\ \text{H}_2\text{O} \\ \text{Steam} \end{array} \right\} \text{H}_2\text{O}$
 $\left. \begin{array}{l} \text{ice} + \text{H}_2\text{O} \\ \text{H}_2\text{O} + \text{Steam} \\ \text{ice} + \text{H}_2\text{O} + \text{Steam} \end{array} \right\} \text{H}_2\text{O}$
 only air (VVO) Dry air. VVO Exhaust gas. H_2O
 no water vapour

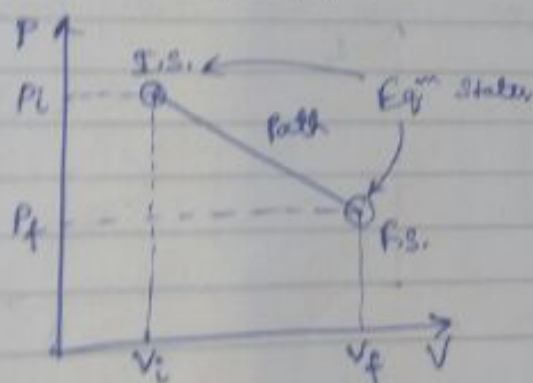
Note - Atmospheric air is an impure substance because the percentage of water vapour content varies from place to place as we have seen that at some places there is a high humidity and at some places there is a low humidity.

Thermodynamic State -

It represents the condition of the system.

Path - Joining of 2 Eq^m states.

Process - Change of path.



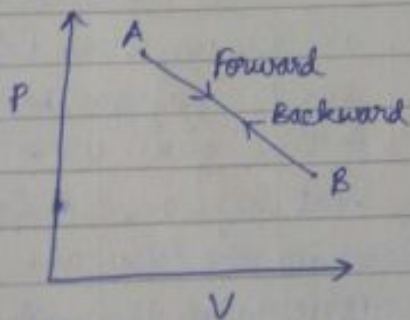
or most of the time we always draw P-V diagram and T-S diagram because they give work and heat resp. on calculating area under the curve and around that whole thermodynamics work.

Why concrete is used along with steel rods in construction?
Because they have almost similar coeff. of thermal expansion.

A process is said to be reversible if system returns to its original state without leaving any effect on the surrounding. For a reversible process, both forward or backward path has to be same. Practically

Reversible and Irreversible Processes

- A process is said to be reversible if system returns to its original state without leaving any effect on the surrounding.
- For the reversible process to occur both forward & backward path has to be same.
- Practically all the process are irreversible.
- Reversible processes are represented by continuous line whereas irreversible processes are represented by dotted line.

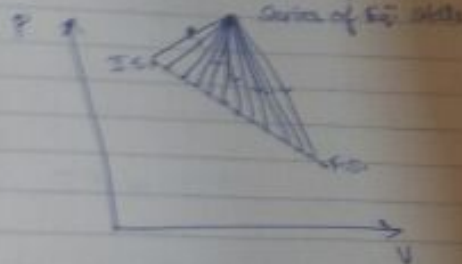


Quasi-static Process

Almost in both condition.

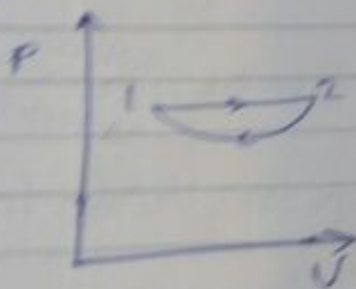
OR
Infinite number of states is a characteristic of quasi-static process.
OR
It is a process which is generated by joining a series of eqm. states.

Note: Quasi-static without friction is a reversible process.

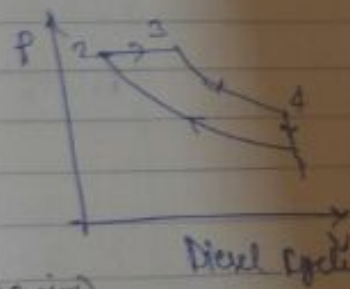


Cyclic Process

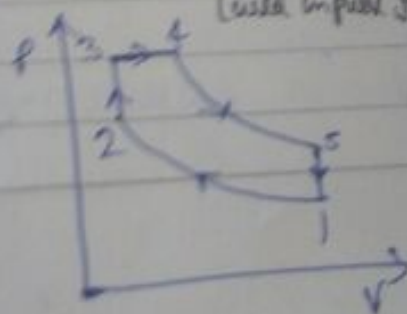
A process is said to be cyclic in which initial state & final state are same, e.g.,



Otto Cycle
(used in petrol engine)



Diesel Cycle



Dual Cycle.

Note: Min. no. of process required to make a cycle are two.

Example of Irreversible Process-

- 1- Friction
- 2- Free Expansion
- 3- Mixing of fluids
- 4- Heat transfer through a finite temp difference.

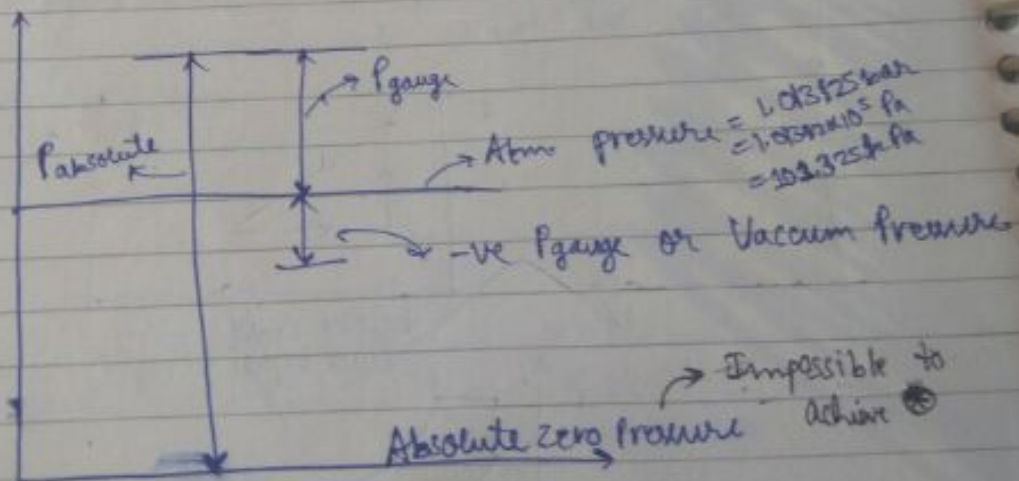
Ideal Gas Equation-

Any gas behaves as an ideal gas at low pressure and high temp. The expression of ideal gas eqⁿ is

$$PV = mRT$$

R is a characteristic gas const.

$$P_{abs} = P_{atm, pressure} + P_{gauge pressure}.$$



$$PV = mRT$$

where P is absolute Pressure
 V is volume
 m is mass
 R is characteristics gas constant
 T is absolute temp.

The other form of eqⁿ is

$$PV = nRT$$

where R is universal gas const.

n is no. of moles.

$$n = \text{moles} = \frac{\text{mass}}{\text{mol. wt.}}$$

$$PV = \text{mass} \left(\frac{R}{\text{mol. wt.}} \right) T$$

$$PV = mRT$$

$$* \quad R = \frac{\bar{R}}{\text{mol. wt.}}$$

$$\bar{R} = 8.314 \text{ kJ/kmol K}$$

Air: Mol. Wt. = 28.96 \approx 29.

$$C_p = 1.005 \text{ kJ/kgK}$$

$$C_v = 0.718 \text{ kJ/kgK}$$

$$R = C_p - C_v = 0.287 \text{ kJ/kgK}$$

$$\gamma = \frac{C_p}{C_v} = 1.4$$

- 1- $t \rightarrow ^\circ\text{C}$
- 2- $T \rightarrow \text{K}$
- * 3- $0^\circ\text{C} \rightarrow 273.15^\circ\text{C}$

* 4- Triple point = $(T.P.)_{\text{temp}} = 273.16\text{K}$ or 0.01°C .

* 5- $(T.P.)_{\text{pressure}} = 4.587\text{mm Hg}$.

$$P = \rho gh = 13.6 \times 1000 \times 9.81 \times 4.587 \times 10^{-3}$$

$$= 611.97\text{ Pa.}$$

$$= 0.611\text{ kPa.}$$

~~Thermodynamic~~ Thermometric Property

The property which helps to find out the value of temp. eg,

- 1- In case of const. volume gas thermometer, pressure will play the role of thermometric property.

$$V = C$$

$$PV = nRT$$

$$P = \left(\frac{nR}{V}\right)T$$

$$P \propto T \text{ i.e. } P \propto T.$$

$$\boxed{T = f(P)}$$

As in the case of constant pressure thermometer, resistance will play the role of thermometric property.

$$R = R_0$$

$$R \propto \frac{1}{V}$$

$$V = \left(\frac{R_0}{R} \right)^{\frac{1}{\alpha}}$$

$$T = \frac{R - R_0}{\alpha R_0}$$

(ii) In the case of electrical resistance thermometer, resistance will play the role of thermometric property.

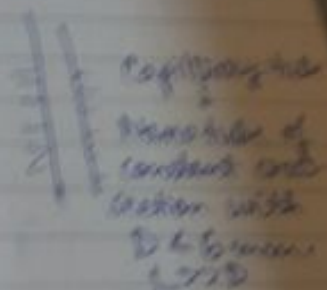
(iii) In the case of thermocouple, EMF or voltage difference will play the role of thermometric property.

(iv) In the case of ordinary thermometer,

priority -

(a) Length

(b) Volume $\rightarrow \frac{V_2}{V_1} = \frac{A_2 L_2}{A_1 L_1}$



Temperature Measurement Scale :-

1- Method used before 1954 :- In this method, two reference pt. are taken into consideration i.e. ice point and steam point.

- Q- Why mercury is used as a fluid in thermometer?
 → Metals are good conductor of heat but most of them are solid at room temp.
 → Only metal which is in liquid state at this temp. is silver.
 → High coeff. of expansion is slight change in temp. is also visible.
 → Alcohol also commonly used.

$$t = ax + b$$

$$t_{ice} = 0^\circ\text{C} \rightarrow x = x_i \rightarrow 0 = ax_i + b$$

$$b = -ax_i$$

$$t_{steam} = 100^\circ\text{C} \rightarrow x = x_s \rightarrow 100 = ax_s - ax_i$$

$$100 = a(x_s - x_i)$$

$$\therefore \left[a = \frac{100}{x_s - x_i} \right]; \left[b = \frac{-100x_i}{x_s - x_i} \right]$$

$$\therefore t = ax + b$$

$$t = \frac{100x}{x_s - x_i} - \frac{100x_i}{x_s - x_i}$$

$$\therefore \left[t = \frac{100(x - x_i)}{(x_s - x_i)} \right]$$

2- Method used after 1954- In this method a unique reference pt. i.e., triple point temp. is taken into consideration eg., in case of constant volume gas thermometer,

$$PV = nRT$$

$$\frac{P(V/n)}{R} = T$$

$$\left[\frac{T \propto P}{V = KP} \right] \text{ --- (1)}$$

At T.P : $T = T_{TP}$
 $P = P_{TP}$

$$T_{TP} = K \cdot P_{TP}$$

$$\left[K = \frac{T_{TP}}{P_{TP}} \right]$$

$$\therefore T = \frac{T_{TP}}{P_{TP}} (P)$$

~~$T = \frac{T_{TP}}{P_{TP}} \left[\frac{P}{P_{TP}} \right]$~~

$$T = T_{TP} \left[\frac{P}{P_{TP}} \right]$$

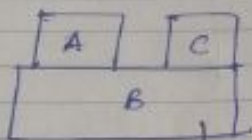
273.16

15-01-17

Zeroth Law of Thermodynamics

→ It was given by R.H. Fowler.

→ According to zeroth law of thermodynamics, when body A is in thermal eq^m with body B and body B is in thermal eq^m with body C separately then body A and C will be in thermal eq^m with each other. The role played by a common body is of thermometer.



$$T_A = T_B \text{ --- (1)}$$

$$T_B = T_C \text{ --- (2)}$$

Compare eqⁿ (1) & (2),

$$\therefore T_A = T_C$$

→ Role played is Thermometer.

→ Note: Zeroth Law provides the concept of thermal eq^m.

* Gibb's Phase Rule -

$$P + F = C + 2$$

↓ Phase ↓ DOF ↓ Components

DOF - It is the minimum no. of independent variables that required to locate or fixed the state of any system.

Case I: Single phase and single component system.

eg. Ice, water, steam.

$$1 + F = 1 + 2$$

$$[F = 2]$$

min. 2 intensive props required to define state.
Can be any two like pressure, temp., etc.

Case II: 2 phase and single component.

eg. Ice + water.

$$2 + F = 1 + 2$$

$$[F = 1]$$

Case III - 3 phase and single component system.

eg. Ice + water + steam.

$$3 + F = 1 + 2$$

$$[F = 0]$$

It is a unique reference point having zero degree of freedom known as Triple point.

* This exists only with water.

* Ideal Gas Thermometer -

It is independent of material of construction.

* 3. Relation -

$$\Delta K = \frac{1}{273.16} \text{ (TP temp of } H_2O \text{)}$$

* Point function and path function -

→ Point function are the variable whose values are independent of the path followed by the system.
eg, pressure, volume.

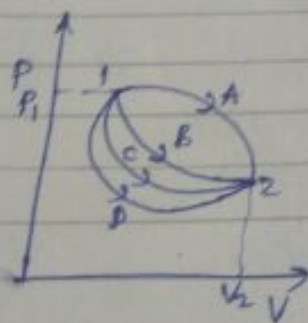
→ Path function - whose value depends on the past history of the system. eg, heat and work.

* Exact Differential - The cyclic integral of the variable is equal to zero. eg, volume, temperature.

* Inexact Differential - The cyclic integral of the variable is not equal to zero. eg, Heat and work.

→ Note: (i) Heat and work are path function and Inexact Differential.

(ii) All properties are point functions and exact differentials.



W_{1-2}
 W_{2-3}
 Q_{1-2}

} Path Function

P_1
 T_1
 V_1

} Point function

∮ Cyclic Integral

∮ d(Variable) = 0 → Exact ^{Property}
≠ 0 → Inexact

$$W = F dx$$

$$F = \frac{F}{A}$$

$$F = PA$$

$$\therefore W = PA dx$$

$$\therefore \boxed{W = \int P dV}$$

$$\oint dP \rightarrow P_F - P_i = P_i - P_i = 0$$

$$\left. \begin{matrix} dP \\ dT \\ dV \end{matrix} \right\} \text{Exact}$$

$$\left. \begin{matrix} dQ \\ dW \end{matrix} \right\} \text{Inexact} \quad \text{or} \quad \left. \begin{matrix} dQ \\ dW \end{matrix} \right\} \text{Inexact}$$

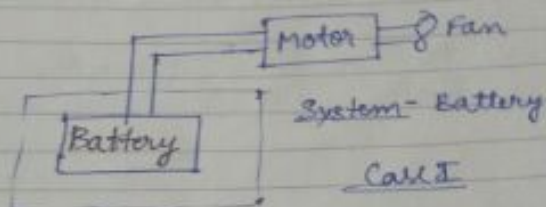
15-01-17

Chapter-2

Energy Interaction

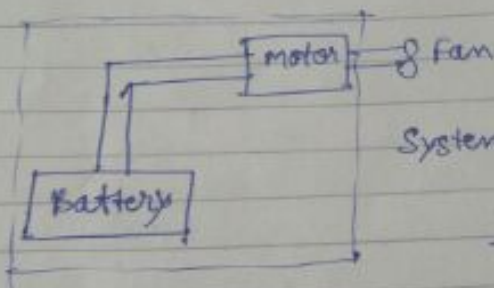
Work-

Work is said to be done by the system if the sole effect on the things external to the system gets reduced to raising of weight (the weight may not be actually raised).



Work ✓

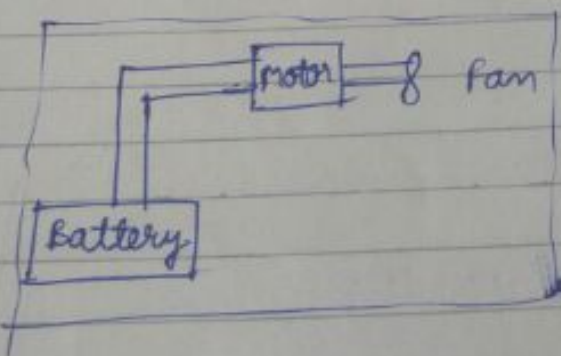
Case I



System: Battery + Motor

Case II

Work ✓



System: Battery + Motor + Fan

Case III

Work X

* Sign Conventions:

W.D by the system = +ve.

W.D on the system = -ve.

Types of work-

1- Closed System work or Non-flow work-

To obtain the closed system work, area under P-V should be projected on volume axis and the mathematical expression of closed system work is

$$W_{\text{closed}} = \int P dV.$$



2- Open system work or Steady work-

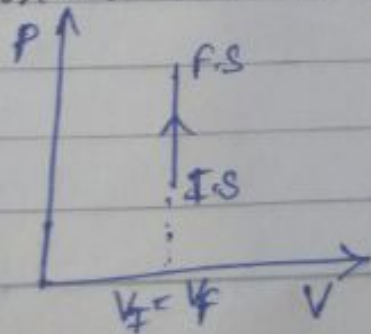
To obtain the open system work, area under PV should be projected on Pressure axis and the mathematical expression is

$$W_{\text{open}} = - \int V dP.$$



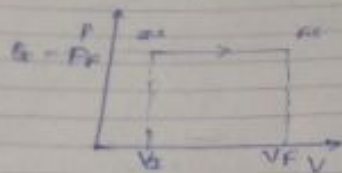
Expression of closed system work for different processes-

1- Constant Volume Process or Isochoric or Isometric-



Zero work.

2- Constant pressure or Isobaric or Isopiestic-



$$W = \int_{V_0}^{V_F} P dV = P \int_{V_0}^{V_F} dV = P [V]_{V_0}^{V_F}$$

$$W_{\text{isobaric}} = P(V_F - V_0)$$

3- Constant temp.

$$PV = nRT$$

$$PV = C$$

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

$$W = \int P dV$$

$$= \int \frac{C}{V} dV$$

$$= C \ln V \Big|_{V_0}^{V_F} = C \ln \frac{V_F}{V_0}$$

$$W = C [\ln V_F - \ln V_0]$$

$$W = C \ln \frac{V_F}{V_0} \quad \text{or} \quad C \ln \frac{P_0}{P_F}$$

$$C = P_0 V_0 = P_F V_F$$

→ Note: In the case of isothermal expansion as the volume increases i.e. by using the pressure of closed system. work for the isothermal process we get two signs (1) work done by the system.

$$V_f > V_i$$

$$\frac{V_f}{V_i} > 1$$

→ In the case of isothermal compression process

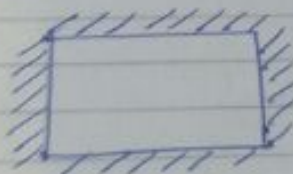
$$V_f < V_i$$

$$\frac{V_f}{V_i} < 1$$



4- Adiabatic Process-

It is a process in which there is no heat interaction takes place between system and surrounding.
eg., insulated vessel.



→ Insulated vessel

It will follow the law $PV^\gamma = C$ where γ is adiabatic index $\neq (\gamma = C_p/C_v)$

$$PV^{\gamma} = C = P_2 V_2^{\gamma} = P_1 V_1^{\gamma}.$$

$$P = \frac{C}{V^{\gamma}}.$$

$$W = \int P dV$$

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

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

$$W = C \int V^{-\gamma} dV.$$

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

$$W = \frac{C}{1-\gamma} [V_2^{-\gamma+1} - V_1^{-\gamma+1}].$$

$$W = \frac{1}{1-\gamma} [C V_2^{1-\gamma} - C V_1^{1-\gamma}].$$

$$W = \frac{1}{1-\gamma} [P_1 V_1^{\gamma} V_2^{1-\gamma} - P_1 V_1^{\gamma} V_1^{1-\gamma}].$$

$$W = \frac{1}{1-\gamma} [P_1 V_2 - P_1 V_1].$$

or,

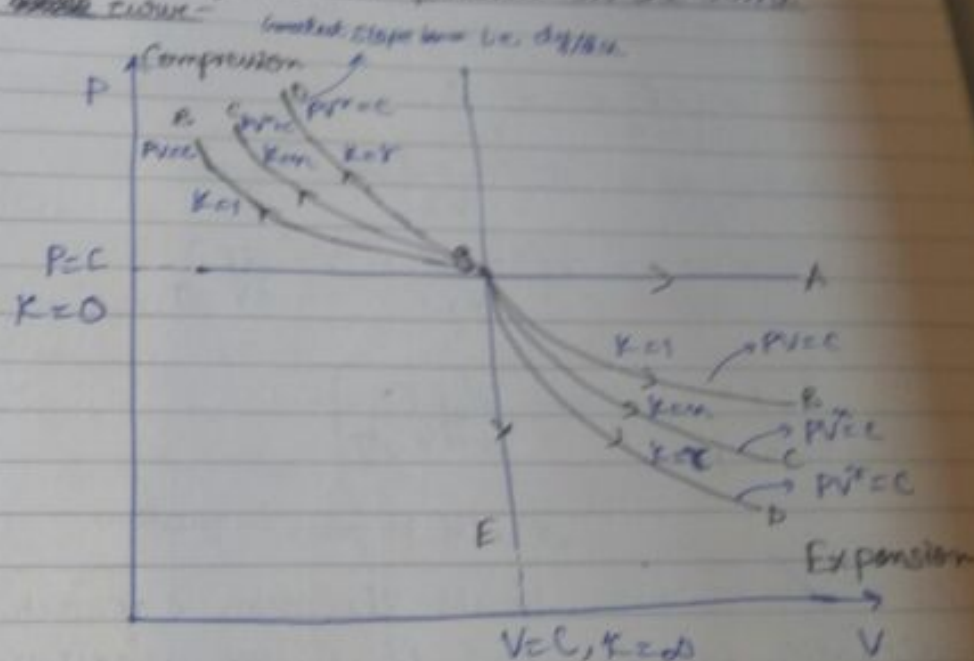
$$W = \frac{P_1 V_2 - P_1 V_1}{\gamma - 1} \quad \text{or} \quad \frac{m R T_2 - m R T_1}{\gamma - 1}$$

5- Polytropic-

It is exactly similar to adiabatic process except some heat interaction takes place. It follows, $PV^n = C$ where n is polytropic index.

$$W = \frac{P_2 V_2 - P_1 V_1}{n-1} \quad \text{or} \quad \frac{m R T_2 - m R T_1}{n-1}$$

Representation of all the processes on the same P-V ~~curve~~ curve-



$$PV^K = C$$

$K=1 \rightarrow PV=C \Rightarrow$ Isothermal process

$K=n \rightarrow PV^n=C \Rightarrow$ Polytropic process

$K=\gamma \rightarrow PV^\gamma=C \Rightarrow$ Adiabatic Process

$$PV^k = C$$

Differentiate

$$d(PV^k) + PkV^{k-1}dV = 0,$$

$$dP V^k = -PkV^{k-1}dV,$$

$$\frac{dP}{dV} = -kPV^{k-1}$$

$$\left[\frac{dP}{dV} = k \left(\frac{-P}{V} \right) \right]_{\text{ok!}}$$

$$k=1 \rightarrow \left(\frac{dP}{dV} \right)_T = \left(\frac{-P}{V} \right),$$

$$k=n \rightarrow \frac{dP}{dV} = n \left(\frac{-P}{V} \right),$$

$$k=\gamma \rightarrow \frac{dP}{dV} = \gamma \left(\frac{-P}{V} \right) = \gamma \left(\frac{dP}{dV} \right)_T,$$

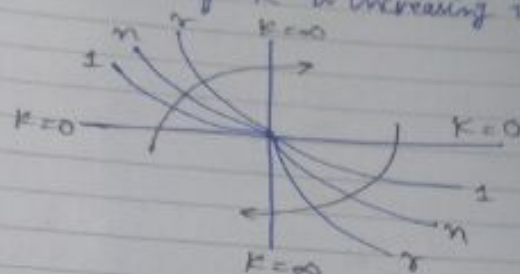
$$\therefore \left[\left(\frac{dP}{dV} \right)_{PV=C} = \gamma \left(\frac{dP}{dV} \right)_T \right]$$

→ It will be given in question.

As $\gamma > n > 1$, hence the max. slope will be of adiabatic process. But it is not necessary that n will lie b/w 1 and γ . It can also ~~inter~~ be greater than γ and less than 1 even -ve. But this is not in syllabus but can be asked.

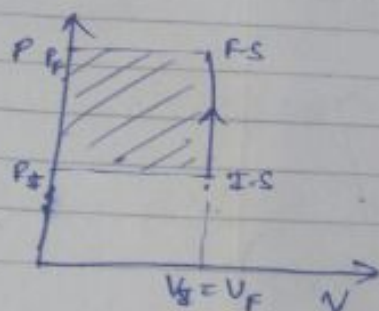
Note: (i) The slope of adiabatic process is γ times of isothermal process.

(ii) The value of K is increasing in clockwise direction.



Expression of open system work for different process-

Case 1- Const. volume process - $V=C$.



$$W = - \int V dP$$

$$= -V \int dP$$

$$= P - V[P]_{P_i}^{P_f}$$

$$= -V(P_f - P_i)$$

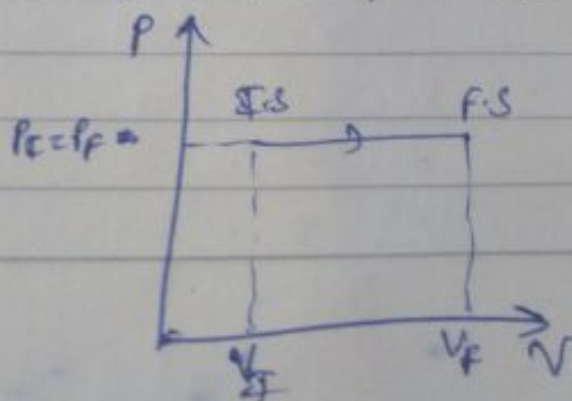
$$\therefore W = -V(P_f - P_i) \quad \text{obj.}$$

$V=C$

$$P_i = \gamma P_i T_i$$

$$P_f = \gamma P_f T_f$$

Case 2- Const. Pressure - $P=C$.



Zero work

Case 3 - Isothermal - $T = C$

$$PV = nRT$$

$$PV = C$$

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

$$W = - \int V dP$$

$$= - \int \frac{C}{P} dP$$

$$= -C \int_{P_i}^{P_f} \frac{dP}{P}$$

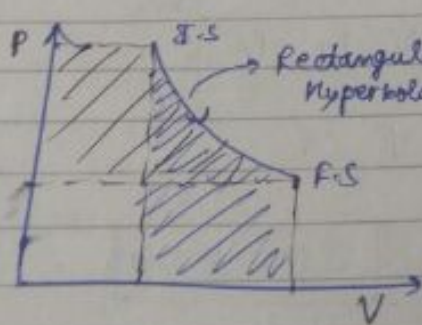
$$= -C [\ln P]_{P_i}^{P_f}$$

$$= -C \ln \frac{P_f}{P_i}$$

$$W = C \ln \frac{P_i}{P_f}$$

$$C = P_i V_i = P_f V_f = nRT_i = nRT_f$$

$$\therefore W = C \ln \frac{P_i}{P_f} \text{ or } C \ln \frac{V_f}{V_i}$$



Rectangular Hyperbola \rightarrow because area under both the axis is same.

- Note: In the case of isothermal process the expansion of closed system work and open system work are same.

$$PV = nRT$$

$$T = C$$

$$PV = C$$

$$\text{Diff. } P dV + V dP = 0$$

$$\int P dV = - \int V dP$$

$$\boxed{W_{\text{closed}} = W_{\text{open}}}$$

Case 4 - Adiabatic Process -

$$PV^\gamma = C$$

$$V^\gamma = \frac{C}{P}$$

$$V = \left(\frac{C}{P} \right)^{1/\gamma}$$

$$W = - \int V dP$$

$$= - \int \left(\frac{C}{P} \right)^{1/\gamma} dP$$

$$= - C^{1/\gamma} \int P^{-1/\gamma} dP$$

$$= - C^{1/\gamma} \left(\frac{P^{1-1/\gamma}}{1-1/\gamma} \right) \Big|_{P_I}^{P_F}$$

$$= - \frac{C^{1/\gamma}}{\frac{\gamma-1}{\gamma}} \left(P_F^{1-1/\gamma} - P_I^{1-1/\gamma} \right)$$

$$= \frac{\gamma}{\gamma-1} \left[- C^{1/\gamma} P_F^{1-1/\gamma} + C^{1/\gamma} P_I^{1-1/\gamma} \right]$$

$$= \frac{\gamma}{\gamma-1} \left[- (P_F V_F)^\gamma P_F^{1-1/\gamma} + C (P_I V_I)^\gamma P_I^{1-1/\gamma} \right]$$

$$= \frac{\gamma}{\gamma-1} \left[-P_F V_F P_F^{-1/\gamma} + P_E V_E P_E^{-1/\gamma} \right]$$

$$= \frac{\gamma}{\gamma-1} (P_E V_E - P_F V_F)$$

$$\therefore \boxed{W = \frac{\gamma}{\gamma-1} [P_E V_E - P_F V_F]}$$

$$\therefore \boxed{W_{open} = \gamma W_{closed}} \quad \text{obj.}$$

Case 5 Polytropic Process.

$$\boxed{W = \frac{n}{n-1} [P_E V_E - P_F V_F]}$$

$$\boxed{W_{open} = n W_{closed}} \quad \text{obj.}$$

~~Heat~~

13- 100°C → 100°F.
300°C → 300°F.

$$P = aT + b.$$

$$100 = a(100) + b.$$

$$300 = 3b.$$

$$\frac{100 - 200}{200} = \frac{a(100) - 200a}{200}$$

$$a = -2.$$

$$9- \quad PV = 9 \text{ MPa}$$

$$T \propto P$$

$$P = 0$$

$$T = 0 \text{ K}$$

$$= -273.15^\circ \text{C}$$

13- 20-
100-
0-
+0°P
+100°F
+300°F

$$0 = -2(T) + 300$$

$$T = +150^\circ \text{C}.$$

1-A

2-C

3-B

4-D

5-A

6-B

7-C

8-C

9-D

10-C

11-B

12-C

13-D

14-D

15-C

16-D

17-C

18-D

19-D

20-18

* Heat -

It is the form of energy interaction due to temp.

$$Q = mC\Delta T.$$

m is mass.

ΔT is the temp diff in $^{\circ}\text{C}$ or K .

C is the specific heat.

In

Specific heat, C - It is the amount of heat which is required to raise the temp. of unit mass by unit temp difference.

$$C = \frac{Q}{m\Delta T} = \frac{Q}{1 \times 1} \frac{\text{kJ}}{\text{kg K}}.$$

→ Note: (i) In the case of solid or liquid there is a single value of specific heat whereas in the case of gases its value depends on the process.

$$\left. \begin{array}{l} C_{\text{H}_2\text{O}} = 4.187 \\ C_p = 1.005 \\ C_v = 0.718 \end{array} \right\} \frac{\text{kJ}}{\text{kg K}}.$$

(ii) The value of adiabatic specific heat is ~~zero~~ zero and isothermal specific heat is infinite.

$$dQ = mC\Delta T.$$

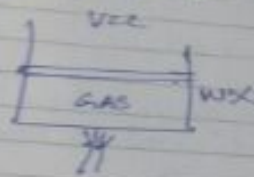
$$C = \frac{dQ}{m\Delta T}.$$

Adiabatic $\rightarrow dQ = 0,$

Isothermal $\rightarrow \Delta T = 0.$

→ Why the value of C_p is always greater than C_v ?

In the case of const. volume process, the complete heat is used to increase the internal energy of the gaseous molecule. Whereas in the case of const. pressure process, some part is used in increasing the internal energy and some in doing external work. Therefore, the value of C_p is always greater than C_v .



$$C_p > C_v$$

Sign Convention-

Heat supplied to the system = +ve.

Heat rejected to ~~the~~ from the system = -ve.

$$Q = m C (T_F - T_I)$$

\downarrow \downarrow \downarrow
 +ve < +ve

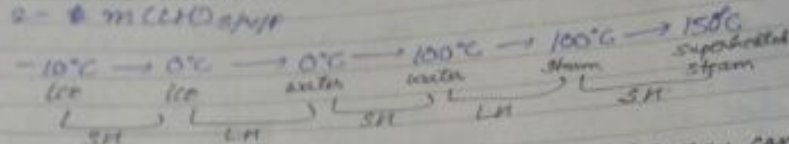
Types of Heat-

1- Sensible Heat - It is a form of heat by the virtue of temp. difference.

2- Latent Heat - Heat required to cause the phase change.

$$1- SH = mCAT$$

$$2- mC\Delta T = \frac{Q}{T}$$



* First law of Thermodynamics or Law of energy conservation

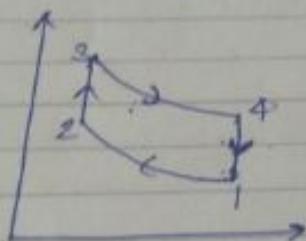
or Joule's law or Quantitative Law -

For a closed system undergoing a cyclic process the net heat interaction is equal to net work interaction when they are expressed in their own units.

OR

Energy can neither be created nor be destroyed rather it converted from one form of energy to another form.

$$\oint \delta Q = \oint \delta W \quad \text{--- (1)}$$



$$Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1} = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

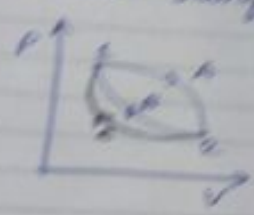
* ~~Eq~~ Eqⁿ no. (1) is applicable for both reversible process and irreversible process.

What is the problem with eq (B)?

The eq (B) is applicable only for a cycle process.
(not applicable for the single process).

Consequences of 1st law of Thermodynamics:-

1- Heat transfer is a path function.



$$1-2-3-1: Q_{12} + Q_{23} + Q_{31} = W_{12} + W_{23} + W_{31} \quad \text{--- (B)}$$

$$1-2-C-1: Q_{12} + Q_{2C} + Q_{C1} = W_{12} + W_{2C} + W_{C1} \quad \text{--- (C)}$$

$$Q_{2C} - Q_{C1} = W_{2C} - W_{C1} \quad \text{--- (D)}$$

$$\text{As } W_{2C} - W_{C1} \neq 0.$$

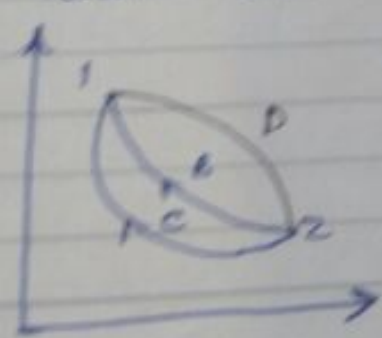
$$\therefore Q_{2C} - Q_{C1} \neq 0.$$

$$\therefore \boxed{Q_{2C} \neq Q_{C1}}.$$

2- Energy is a property.

Using eq no. (D),

$$Q_{2C} - Q_{C1} = W_{2C} - W_{C1}$$



$$\cancel{Q_{2C} - Q_{C1}} - \cancel{W_{2C} - W_{C1}} = Q_{2C} - W_{2C} = Q_{2C} - W_{2C}$$

$$\delta Q - \delta W = dE$$

$$\boxed{\delta Q = dE + \delta W}$$

→ Exact Differential

* U is not just a thermal energy.

$$dE = d(\underbrace{KE}_{\text{Macroscopic Form}} + \underbrace{PE}_{\text{Microscopic Form}} + U)$$



$$dE = dU$$

Assumption: Neglect KE , PE .

$$\therefore \boxed{\delta Q = dU + \delta W}$$

Condition for applying PdV work-

- ✓ It should cross the boundary.
- ✓ It should be a reversible process.
- ✓ It should be a closed system.

$$\boxed{\delta Q = dU + PdV} \quad \text{--- (4)}$$

Eqⁿ (4) is applicable for a closed system and reversible process.

3- Energy of an isolated system is constant.

$$\delta Q = dE + \delta W$$

No energy interaction means work & heat

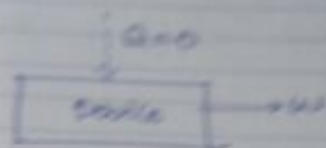
$$\boxed{dE = 0} \quad \text{Obj.}$$

$$E_f - E_i = 0 \quad \text{Obj.}$$

$$\boxed{E_f = E_i}$$

② We have calculated this from random values given but we apply thermodynamic relation (1) to find direction and find sign in the 4th or 5th part.

Prpt-1: Perpetual Motion Machine of first kind.



Perpetual motion machine of first kind is impossible because it violates first law of thermodynamics.

It is impossible to construct a device which produces work continuously without consuming any other form of energy.

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

$$\downarrow \quad \quad \downarrow$$

$$0 \quad \quad 0$$

Expression of Heat for different Processes -

1- Constant Volume -

$$\delta Q = dU + PdV$$

$$V = C$$

$$dV = 0.$$

$$\boxed{\delta Q = dU} \text{--- (A)}$$

$$\boxed{\delta Q = mC\Delta T} \text{--- (B)}$$

Compare eq (A) & (B), $\boxed{dU = mC\Delta T} \text{--- (C)}$

→ Note: The above expression is applicable for all processes because it contains all point functions.
As internal energy is a function of temperature only for ideal gas.

* Enthalpy-

It represents the total heat content of the system.
The mathematical expression of enthalpy is

$$H = U + PV$$

Dimension: Joule.

$$\downarrow$$
$$N \times m$$

$$\rightarrow \text{mass} \times \text{acc}^n \times \text{disp.}$$

$$\rightarrow \text{kg} \frac{\text{m}}{\text{s}^2} \times \text{m}$$

$$\text{kg m}^2/\text{s}^2 = \text{ML}^2\text{T}^{-2}$$

Specific Enthalpy- It is a summation of specific internal energy and flow work.

$$\text{Specific Enthalpy, } h = \frac{U}{m} + \frac{PV}{m}$$

$$h = U + PV$$

Flow work.

Flow work - It is the amount of work which is required to displace an infinitely fluid element into or out of control volume.

Note: (i) Control mass is also known as closed system.
 (ii) Control mass and control volume as open system.
 (iii) Boundary of control volume is known as control surface.



Case II - Pressure const.

$$\delta Q = dU + PdV$$

$$P = C$$

$$\delta Q = dU + d(PV)$$

$$\delta Q = d(U + PV)$$

$$\delta Q = dH \quad \text{--- (A)}$$

$$\delta Q = mC_p dT \quad \text{--- (B)}$$

Compare (A) & (B)

$$\boxed{dH = mC_p dT}.$$

→ Note : (i) The above expression is applicable for all processes because it contains all properties.
 (ii) Enthalpy is a function of temp. for ideal gas.

Case III - Const. Temperature.

$$T = C$$

$$\delta Q = dU + \delta W.$$

$$T = C$$

$$dT = 0.$$

$$mCv dT = 0.$$

$$dU = 0.$$

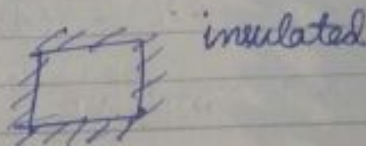
$$\therefore \boxed{\delta Q = \delta W}.$$

$$\boxed{\delta Q = \delta W = \frac{C \ln V_F}{V_I} \text{ or } \frac{C \ln P_I}{P_F}} \quad \leftarrow \text{Same for all.}$$

$$C = P_I V_I = P_F V_F = mRT_I = mRT_F$$

Case IV - Adiabatic Process.

$$dQ = 0.$$



It is a process in which there is no heat interaction takes place b/w system and surrounding, eg., insulated vessel.

→ ^{**} Prove that the value of heat is zero for adiabatic process.

$$\delta Q = dU + \delta W.$$

$mCv dT$

Relationship b/w C_p , C_v , R and γ -

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

$$C_p = \gamma C_v$$

$$R = C_p - C_v$$

$$R = \gamma C_v - C_v$$

$$R = C_v(\gamma - 1)$$

$$C_v = \frac{R}{\gamma - 1} \quad \text{okj.}$$

$$C_p = \frac{\gamma R}{\gamma - 1} \quad \text{okj.}$$

$$dQ = dU + dW.$$

$$= m C_v (T_F - T_I) + \frac{P_F V_F - P_I V_I}{\gamma - 1}.$$

$$= \frac{m R}{\gamma - 1} (T_F - T_I) + \frac{P_F V_F - P_I V_I}{\gamma - 1}.$$

$$= \frac{m R T_F - m R T_I}{\gamma - 1} + \frac{P_F V_F - P_I V_I}{\gamma - 1}.$$

$$= \frac{P_F V_F - P_I V_I}{\gamma - 1} + \frac{P_I V_I - P_F V_F}{\gamma - 1}.$$

$$\therefore dQ = \boxed{\text{Zero}}.$$

→ Prove that $PV^\gamma = \text{const.}$ for reversible adiabatic process.

$$dQ = dU + dW.$$

~~dQ = 0~~

$$mC_v dT = -PdV.$$

$$dT = mC_p dT.$$

$$\frac{-PdV}{dT} = C$$

$$\frac{dT}{-PdV} = \frac{C_p}{C_v} = \gamma.$$

$$dT = -\gamma \frac{PdV}{P}.$$

$$dT = -\gamma \frac{dV}{V}.$$

$$\frac{PdV + VdP}{\gamma R} = -PdV$$

$$PdV + VdP = -PdV(\gamma - 1)$$

$$PdV + VdP = -\gamma PdV + PdV$$

$$C_p - C_v = R.$$

$$(\gamma - 1)C_v = R$$

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

$$PV = nRT.$$

$$T = \frac{PV}{nR}.$$

$$dT = \frac{d(PV)}{nR}.$$

$$dQ = dU + dW$$

For Adiabatic, $dQ = 0$.

$$dU = -dW.$$

$$mC_v dT = -PdV.$$

$$PV = nRT.$$

$$T = \frac{PV}{nR}.$$

$$dT = \frac{d(PV)}{nR}$$

$$\frac{PdV + VdP}{nR} = dT.$$

$$mC_v dT = -PdV.$$

$$\gamma C_v (PdV + VdP) = -PdV$$

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

$$PdV + VdP = (\gamma - 1)PdV$$

$$PdV + VdP = -\gamma PdV + PdV$$

$$-\gamma PdV = VdP.$$

$$\frac{dP}{P} = -\gamma \frac{dV}{V}$$

$$\ln P = -\gamma \ln V + \ln k$$

$$\ln P = \ln \frac{k}{V^\gamma}$$

$$PV^\gamma = k.$$

Proof - $PV^\gamma = \text{Constant}$

$$dS_Q = dU + PdV.$$

Rev. Adiabatic $\rightarrow S_Q = 0.$

$$dU + PdV = 0$$

$$dU = -PdV.$$

$$\boxed{mC_V dT = -PdV} \quad \text{--- (1)}$$

$$H = U + PV$$

$$dH = dU + PdV + VdP.$$

$$dH = S_Q + VdP.$$

$$\boxed{dS_Q = dH - VdP} \quad \text{--- (2)}$$

Rev. Adiabatic - $S_Q = 0.$

$$dH = VdP.$$

$$mC_P dT = VdP. \quad \text{--- (3)}$$

$$\text{(3)} \div \text{(1)}$$

$$\frac{C_P}{C_V} = - \frac{VdP}{PdV} = \gamma.$$

$$\gamma PdV = -VdP.$$

$$- \frac{dP}{P} = \gamma \frac{dV}{V}$$

$$-\ln P = \gamma \ln V + \ln C$$

$$\ln P + \gamma \ln V = \ln C$$

$$\ln PV^\gamma = \ln C$$

$$\boxed{PV^\gamma = C.}$$

Q.5.10. Q.11

Prove that -

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

$$\frac{T_F}{T_I} = \left(\frac{P_F}{P_I}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_I}{V_F}\right)^{\gamma-1}$$

For a Rev. Adiabatic Process,

$$PV^\gamma = C.$$

$$PV = mRT.$$

$$V = mR\left(\frac{T}{P}\right)$$

$$P\left(\frac{T}{P}\right)^\gamma = C.$$

$$P^{1-\gamma} \cdot T^\gamma = C.$$

$$P_F^{1-\gamma} \cdot T_F^\gamma = C = P_I^{1-\gamma} \cdot T_I^\gamma$$

$$\left(\frac{T_F}{T_I}\right)^\gamma = \left(\frac{P_I}{P_F}\right)^{\gamma-1}$$

$$\left(\frac{T_F}{T_I}\right)^\gamma = \left(\frac{P_F}{P_I}\right)^{\gamma-1}$$

$$\boxed{\frac{T_F}{T_I} = \left(\frac{P_F}{P_I}\right)^{\frac{\gamma-1}{\gamma}}} \quad \text{--- (A)}$$

$$PV = mRT.$$

$$P = mR\left(\frac{T}{V}\right)$$

$$\left(\frac{T}{V}\right) \cdot V^\gamma = C$$

$$T \cdot V^{\gamma-1} = C$$

$$T_F V_F^{\gamma-1} = T_I V_I^{\gamma-1}$$

$$\boxed{\left(\frac{T_F}{T_I}\right) = \left(\frac{V_I}{V_F}\right)^{\gamma-1}} \quad \text{--- (B)}$$

Case 5- Polytropic Process-

$$\begin{aligned}dQ &= dU + dW \\&= mC_v(T_2 - T_1) + \frac{P_2 V_2 - P_1 V_1}{n-1} \\&= \frac{mR}{\gamma-1} (T_2 - T_1) + \frac{P_2 V_2 - P_1 V_1}{n-1} \\&= \frac{P_2 V_2 - P_1 V_1}{\gamma-1} + \frac{P_2 V_2 - P_1 V_1}{n-1} \\&= \frac{P_2 V_2 - P_1 V_1}{n-1} - \frac{P_2 V_2 - P_1 V_1}{\gamma-1} \\&= (P_2 V_2 - P_1 V_1) \left(\frac{1}{n-1} - \frac{1}{\gamma-1} \right) \\&= (P_2 V_2 - P_1 V_1) \left(\frac{\gamma - n}{(n-1)(\gamma-1)} \right) \\&= (P_2 V_2 - P_1 V_1) \left(\frac{\gamma - n}{(n-1)(\gamma-1)} \right) \\&= R \left(\frac{P_2 V_2 - P_1 V_1}{n-1} \right) \left(\frac{\gamma - n}{\gamma - 1} \right)\end{aligned}$$

div:

$$\boxed{dQ = \left(\frac{\gamma - n}{\gamma - 1} \right) W_{\text{closed}}}$$

Polytropic Specific Heat-

$$dQ = m C_{AT} = \left(\frac{\gamma - n}{\gamma - 1} \right) W_{\text{closed}}$$

$$dQ = \left(\frac{\gamma - n}{\gamma - 1} \right) \left(\frac{P_2 V_2 - P_1 V_1}{n-1} \right)$$

$$= \left(\frac{\gamma - n}{\gamma - 1} \right) \left(\frac{mR T_2 - mR T_1}{n-1} \right)$$

$$dQ = \left(\frac{\gamma - n}{\gamma - 1} \times \frac{mR}{n-1} \right) (T_2 - T_1).$$

$$= m C_v \left(\frac{\gamma - n}{n-1} \right) (T_2 - T_1).$$

$$= m C_v \left(\frac{n - \gamma}{n-1} \right) (T_1 - T_2).$$

$$\therefore dQ = m C \Delta T = m C_v \left(\frac{n - \gamma}{n-1} \right) (T_1 - T_2).$$

$$\therefore \boxed{C_{\text{polytropic}} = C_v \left(\frac{n - \gamma}{n-1} \right)}.$$

This is only ~~valid~~ when ~~$\gamma > n$~~ $n > \gamma$.
for $\gamma > n > 1 \rightarrow C_{PV} = \text{const.} = -ve.$

* Meyer's Eqⁿ $\rightarrow C_p - C_v = R$. Proof.
For 5 marks.

$$H = U + PV.$$

$$dH = dU + d(PV).$$

$$dH = dU + d(mRT).$$

$$m C_p dT = m C_v dT + m R dT$$

$$\boxed{C_p - C_v = R}.$$

→ Note: The value of polytropic specific heat is negative if $\gamma > n > 1$.

* Important points regarding Heat and Work -

- Similarities -

- 1- Both are path function.
- 2- Both are boundary phenomenon.
- 3- Both are inexact differential.
- 4- Both are Energy in transit or Transient Phenomenon.
"Boundary"

- Differences -

- 1- All the forms of energy interaction are work interaction except energy interaction due to temp.
- 2- Area under PV provides work interaction and area under TS provides heat interaction.

→ Note: (i) All the work producing devices are shown in clockwise dirⁿ on PV and TS. eg, Carnot cycle, Otto cycle, Rankine cycle.

(ii) All the work absorbing devices are shown in anti-clockwise dirⁿ on PV and TS. eg, Reversed Carnot cycle, Reversed Brayton cycle.

(Q. 15)

Question 1 - A spherical balloon of 1m dia contains a gas at 150 kPa. The gas inside the balloon is filled until the pressure reaches 450 kPa. During the process of heating, the pressure of the gas inside the balloon is proportional to the cube of the dia ($P \propto d^3$) of balloon, then find out the work done by the gas inside the balloon.

Approach-1-

$$P = K D^3$$

$$V = \frac{\pi}{6} D^3$$

$$P \propto V$$

$$PV^{-1} = \text{constant}$$

(*)

Polytropic process with $n = -1$.

Approach-2-

$$V = \frac{4}{3} \pi R^3$$

$$V = \frac{\pi}{6} D^3$$

$$dV = \frac{\pi}{6} 3D^2 (dD)$$

Not an incorrect. Just not to get confused with d and

$$\boxed{dV = \frac{\pi D^2 (dD)}{2}} \quad \text{--- (1)}$$

$$P = KD^3 \quad \text{--- (2)}$$

$$W = \int P dV = \int KD^3 \frac{\pi D^2 dD}{2}$$

$$= \frac{K\pi}{2} \int_{D_1}^{D_2} D^5 dD$$

$$= \frac{K\pi}{2 \times 6} [D^6]_{D_1}^{D_2}$$

$$= \frac{K\pi}{12} [D_2^6 - D_1^6]$$

$$W = \frac{F \pi}{12} [D_2^3 - (D_1^3)]$$

$$P_1 = F D_1^2$$

$$150 = K (1)^4$$

$$K = 150 \text{ kPa/m}^2$$

$$P_2 = F D_2^2$$

$$450 = 150 D_2^3$$

$$D_2 = 1.44 \text{ m}$$

$$W = 310 \text{ kJ}$$

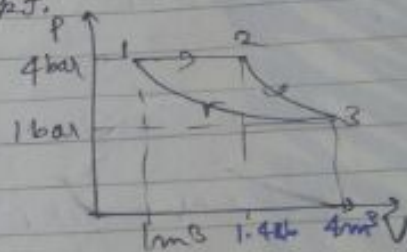
2- A system undergoes quasi-static process as shown in fig. Process 1-2 is isobaric, 2-3 is a polytropic process with $n=1.4$, 3-1 is isothermal, then find out
(i) Volume of the system at pt-2 in m^3 .
(ii) Net work for the cycle in kJ.

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

$$4 \times V_1^{1.4} = 1 \times V_2^{1.4}$$

$$V_1^{1.4} = 0.4$$

$$V_1 = 1.486 \text{ m}^3$$



$$W = 4(0.486) + \frac{P_2 V_2 - P_1 V_1}{0.4} + 4 \ln \frac{1}{4}$$

$$= 1.944 + \frac{4 \times 1.486 - 1 \times 4}{0.4} - 5.545$$

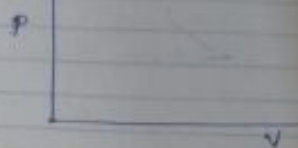
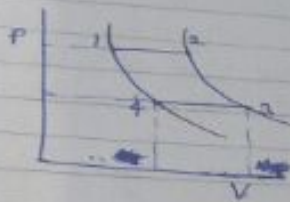
$$= 1.259 \times 10^5 \text{ Pa m}^3$$

$$= 125.9 \text{ kJ}$$

2. As shown

3- Prove the validity or otherwise of the statement.

"For a perfect gas the work done by constant pressure expansion from any point on a given isothermal to another given isothermal is constant."



$$\begin{aligned} & P_1(V_2 - V_1) \\ & P_4(V_3 - V_4) \\ & P_1V_2 - P_1V_1 \\ & P_4V_3 - P_4V_4 \\ & P_4(V_3 - V_4) \end{aligned} \quad (1)$$

$$\begin{aligned} PV &= k, \quad (2) \\ P_1V_1 &= P_4V_4, \quad W_1 = mR(T_2 - T_1) \\ P_2V_2 &= P_3V_3, \quad W_2 = mR(T_2 - T_1) \\ P_1V_2 &= P_4V_3 \end{aligned}$$

$$(1-2): P = C \rightarrow W_{1-2} = P(V_2 - V_1) = P_1(V_2 - V_1) = P_1V_1 \left(\frac{V_2}{V_1} - 1 \right) \quad (A)$$

$$(3-4): P = C \rightarrow W_{3-4} = P(V_4 - V_3) = P_3(V_4 - V_3) = P_3V_3 \left(\frac{V_4}{V_3} - 1 \right) \quad (B)$$

$$(1 \rightarrow 2): P = C \rightarrow PV = mRT \Rightarrow V = \left(\frac{mR}{P} \right) T \Rightarrow V_1 T_1 = V_2 T_2 \Rightarrow \frac{V_2}{V_1} = \frac{T_2}{T_1}$$

$$P = C \rightarrow PV = mRT \Rightarrow V = \left(\frac{mR}{P} \right) T \Rightarrow V_3 T_3 = V_4 T_4 \Rightarrow \frac{V_4}{V_3} = \frac{T_4}{T_3} = \frac{T_2}{T_1}$$

$$\therefore \frac{V_2}{V_1} = \frac{V_4}{V_3} \quad (C)$$

From (A), (B) & (C),

$$W_{1-2} = W_{3-4}$$

Q4- 10 marks

Air at an initial temp. of 300K and volume of 0.002m^3 is contained in a piston cylinder arrangement at this stage a linear spring which have a spring constant of ~~100~~ 10kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas causing the piston to rise and to compress the spring until the final volume inside the cylinder is 0.003m^3 . The area of the piston is 0.02m^2 and the atm. pressure is 100kPa . Then find out the final pressure inside the cylinder and the apparatus is surrounded by atm. air.

$$T_1 = 300\text{K} \quad V_1 = 0.002\text{m}^3$$

$$K = 10\text{kN/m}$$

$$V_2 = 0.003\text{m}^3$$

$$A = 0.02\text{m}^2$$

$$P_{\text{atm}} = 100\text{kPa}$$



~~ex~~

$$0.001 = A \cdot 0.02 \times x$$

$$x = 0.05$$

$$P_{\text{sp}} = \frac{F}{A}$$

$$= \frac{kx}{A}$$

$$= \frac{10 \times 10^3 \times 0.05}{0.02}$$

$$= \frac{10 \times 10^3 \times 10^3}{10^2}$$

$$= 10$$

$$P_{\text{sp}} = \frac{kx}{A}$$

$$= \frac{10 \times 0.05}{0.02} = 25\text{kPa}$$

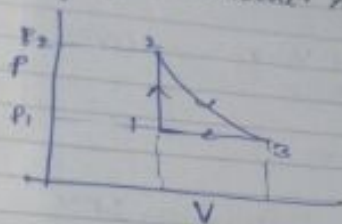
$$P_1 V_1 = nRT_1$$

$$P_1 \times 0.002 = nR$$

$$P_f = P_{\text{atm}} + P_{\text{sp}} = \boxed{125\text{kPa}}$$

(IES 15 marks)

Q5 - An ideal gas is heated at constant volume until its temp. is 3 times the original temp. Then it is expanded isothermally to reach its original pressure. The gas is then cooled at constant pressure till it is restored to its original state. Determine the net work done / kg of gas in terms of gas constant. Assume $T_1 = 350 \text{ K}$.



$$T_1 = 350 \text{ K}$$

$$T_2 = 1050 \text{ K}$$

$$T_3 = 1050 \text{ K}$$

$$P_1 V_1 = m R T_1$$

$$P_1 V_1 = m R (350) \quad \frac{P_2}{P_1} = \frac{1}{3}$$

$$P_2 V_1 = m R (1050) \quad P_2 =$$

$$W = m R T_2 \ln \frac{V_3}{V_2} - P_1 (V_3 - V_1)$$

$$= m R T_2 \ln \frac{P_2}{P_1} - P_1 (V_3 - V_1)$$

$$= m R (1050) \times 1.0986 - 2 P_1 V_1$$

$$\boxed{\frac{W}{m} = 453.53 \text{ R}}$$

$$P_2 V_2 = P_3 V_3$$

$$\frac{3}{2} V_2 = P_1 V_3$$

$$V_3 = 3 V_1$$

(IAS & IES)

Q6 - An insulated pressure vessel is divided into two parts by a movable piston. One part of the vessel is occupied by an ideal gas having a Pressure P_1 , V_1 and temp. T_1 . The other part is occupied by the same gas having P_2 , V_2 and T_2 . The partition is removed and the 2 parts are mixed then show that the final pressure P_3 and Temp T_3 is -

$$P_3 = \frac{P_1 V_1 + P_2 V_2}{V_1 + V_2}$$

$$T_3 = \frac{P_1 V_1 + P_2 V_2}{\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2}}$$

$$\left[\frac{P_1 V_1}{T_1} \right] + \left[\frac{P_2 V_2}{T_2} \right] \rightarrow \left[\frac{P_3 (V_1 + V_2)}{T_3} \right]$$

$$P_1 V_1 = n_1 R T_1 \quad \therefore P_1 V_1 + P_2 V_2 = n_1 R T_1 + n_2 R T_2$$

$$P_2 V_2 = n_2 R T_2$$

$$P_3 (V_1 + V_2) = (n_1 + n_2) R T_3$$

$$P_3 \left(\frac{n_1 R T_1}{P_1} + \frac{n_2 R T_2}{P_2} \right) = (n_1 + n_2) R T_3$$

$$P_3 \left(\frac{n_1 T_1 P_2 + n_2 T_2 P_1}{P_1 P_2} \right) = (n_1 + n_2) T_3$$

$$\frac{T_1 + T_2}{2} = \frac{P_1 V_1 + P_2 V_2}{n R}$$

$$Q = m_1 c (T_F - T_1) = m_2 c (T_F - T_2)$$

$$m_1 T_F - m_1 T_1 = m_2 T_F - m_2 T_2$$

$$(m_2 - m_1) (T_2 - T_1) = (m_2 - m_1) T_F$$

$$T_2 - T_1 = T_F$$

$$P_3 (V_1 + V_2) = (n_1 + n_2) R (T_2 - T_1)$$

$$= n_1 R T_2 - n_2 R T_1 + n_1 R T_1 + n_2 R T_2$$

I -

Mass Conservation, $m_3 = m_1 + m_2$.

Energy conservation, $m_3 u_3 = m_1 u_1 + m_2 u_2$.

$$u = C_v T.$$

$$m_3 C_v T_3 = m_1 C_v T_1 + m_2 C_v T_2.$$

$$m_3 T_3 = m_1 T_1 + m_2 T_2.$$

$$PV = mRT.$$

($N_1 + N_2$)

$$\frac{P_3 V_3}{R} = \frac{P_1 V_1}{R} + \frac{P_2 V_2}{R}$$

$$P_3 = \frac{P_1 V_1 + P_2 V_2}{V_1 + V_2}$$

~~$P_3 V_3 = m_3 R T_3$~~

$$~~P_3 V_3 = m_3 R T_3.~~$$

$$~~m_3 = \frac{P_3 V_3}{R T_3}~~$$

$$P_3 V_3 = m_3 R T_3$$

$$T_3 = \frac{(P_1 V_1 + P_2 V_2) (C_v + R)}{V_1 + V_2} \frac{(m_1 + m_2)}{R}$$

$$T_3 = \frac{P_1 V_1 + P_2 V_2}{\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2}}$$

II

$$dQ = dU + dW$$

$$dU = 0.$$

$$U_1 - U_2 = 0 \Rightarrow U_3 = U_1 + U_2.$$

III

No. of moles

IV

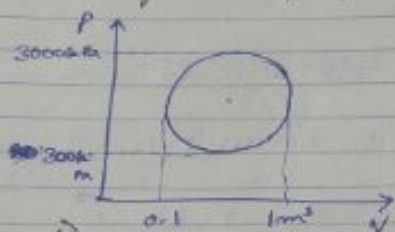
Heat

V

Mass conservation

QPS 10 marks

7- An imaginary engine receives heat and performs work on a slowly moving piston at such a rate that the cycle of operation for 1 kg of working fluid can be represented as a circle of 10 cm dia on PV diagram on which $p_{\text{min}} = 300 \text{ kPa}$ and $v_{\text{min}} = 0.1 \text{ m}^3/\text{kg}$. Determine the work done of each kg of working fluid.



$$A = \frac{\pi}{4} D^2$$

$$\frac{\pi}{4} \times 10^2 = 78.4 \text{ cm}^2$$

$$78.4 \times 300 \text{ kPa} \times 0.1 \frac{\text{m}^3}{\text{kg}}$$

$$2356 \text{ kJ}$$

QPS 15 marks

8- A 1g nitrogen undergo following sequence of processes in a piston cylinder arrangement.

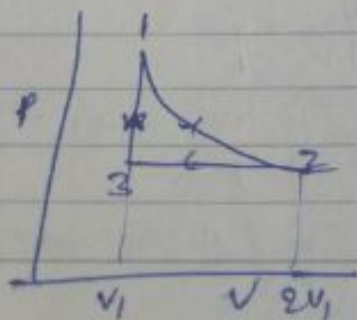
I - An adiabatic expansion in which vol. doubles.

II - A constant pressure process in which vol. is reduced to its initial value.

III - A constant volume process back to its initial state.

Represent the cycle on PV diagram and calc. the net work done.

$$T_1 = 150^\circ\text{C}, P_1 = 5 \text{ atm}, R = 297 \text{ J/kgK}, \gamma = 1.4, \\ = 5.05 \text{ bar}$$



$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$5 = P_2 \times 2$$

$$5.05 (V_1)^{1.4} = P_2 \times (2V_1)^{1.4}$$

$$P_2 = \frac{5.05}{2^{1.4}} = 1.894 \text{ atm}$$

$$P_1 V_1 = nRT$$

$$5 \times 10^5 \times V_1 = 10^3 \times 287 \times 293$$

$$V_1 = 25.126 \text{ m}^3$$

$$V_2 = 50.252 \text{ m}^3$$

$$W = \frac{P_1 V_1 - P_2 V_2}{0.4} = \frac{5 \times 25.126 - 1.234 \times 50.252}{0.4}$$

$$= \frac{5 \times 25.126 - 1.234 \times 50.252}{0.4} = \frac{1.234 \times 25.126}{0.4}$$

$$\therefore W = 22.543 \text{ J}$$

(Ans 15 marks)

9- A rigid insulated tank of 3 m^3 volume is divided into 2 compartments. One compartment having vol. of 1 m^3 ideal gas having $P_1 = 0.1 \text{ MPa}$ and $T_1 = 300 \text{ K}$, while the 2nd compartment having $V_2 = 2 \text{ m}^3$, $P_2 = 1 \text{ MPa}$, $T_2 = 1000 \text{ K}$ having same ideal gas. If the partition is removed then calculate, final temp. and pressure of the gas.

$$P_F = \frac{P_1 V_1 + P_2 V_2}{V_3}$$

$$= \frac{0.1 \times 1 + 1 \times 2}{3}$$

$$= \frac{2.1 \times 10^5}{3}$$

$$P_F = 0.7 \text{ MPa}$$

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

$$= \frac{2.1}{\frac{0.1}{300} + \frac{2}{1000}}$$

$$T_F = 900 \text{ K}$$

Gas 15 marks

10- A fluid is confined in a cylinder by a spring loaded frictionless piston so that pressure of a fluid is a linear fⁿ of volume ($P = a + bV$) where a & b are constants. Internal energy of a fluid is given by an equation, $U = 34 + 3.15PV$, where U is in kJ, P is kPa, and V is in m³. If the fluid changes from an initial state of $P_1 = 170$ kPa, $V_1 = 0.03$ m³ to a final state of $P_2 = 400$ kPa, $V_2 = 0.06$ m³. Find out the mag. of work and heat transfer.

$$P = a + bV.$$

$$dW = PdV.$$

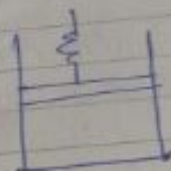
$$= \int (a + bV) dV$$

$$= aV + \frac{bV^2}{2} \Big|_{V_1}^{V_2}$$

$$\underline{= a}$$

$$= 400 \times 0.03 - \frac{230}{2} (0.03)^2$$

$$W = 8.55 \text{ kJ.}$$



$$170 = a + b(0.03)$$

$$400 = a + b(0.06)$$

$$- b(0.03) = 230$$

$$b = \frac{-230}{0.03}$$

$$170 = a - 230$$

$$a = 400.$$

$$\underline{dU = 3.15} \quad dU = 3.15 (400 \times 0.06 - 170 \times 0.03)$$

$$Q = 68.085 \text{ kJ.}$$

Heat capacity $\rightarrow mC \rightarrow C_p = \frac{2.093 + 41.87}{t + 100} \text{ J/}^\circ\text{C}$

$$dQ = \int C_p dt$$

$$= \int \frac{2.093 + 41.87}{t + 100} dt$$

$$= 2.093t + 41.87 \ln(t + 100) \Big|_0^{100}$$

$$= 2.093 \times 100 + 41.87 \ln\left(\frac{200}{100}\right)$$

$$= 238.32 \text{ J}$$

$$W = 1.01 \times 10^5 \times 400 \times 10^{-6}$$

$$= 40.4 \text{ J}$$

$$dQ = dU + dW$$

$$dU = 238.32 - 40.4 = 197.92 \text{ J}$$

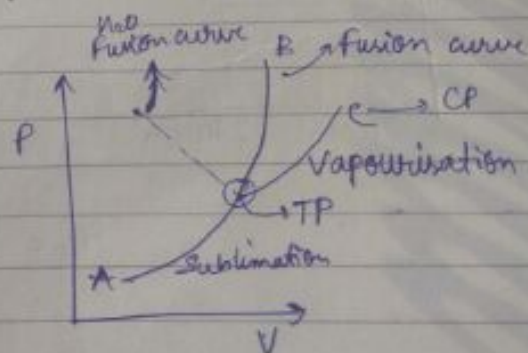
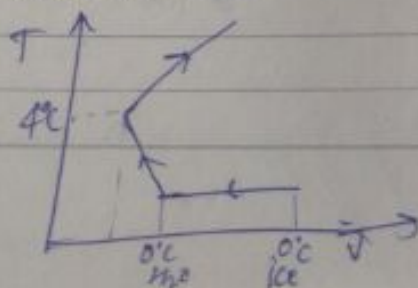
$$\approx 1 \times 10^4 \times 30$$

Note: Whenever word "battery" is there then there is only work interaction.

$$12- \rho = \frac{m}{\text{Volume}}$$

\rightarrow max at 4°C

Volume min. at 4°C



→ Note that the density of water is max. at 4°C . Therefore, during freezing it will expand because the slope of the fusion curve is exceptionally -ve for water.

24. Triple point is a point on PT curve and line on PV curve or P-V-T surface.

Triple point \rightarrow Point

25- $dQ = \frac{r-n}{r-1} W_{\text{cloud}}$

$r > n > 1$

$r = 1.4$

$n = 1.2$

$dQ = \frac{(1.4-1.2)}{1.4-1} W_{\text{cloud}}$

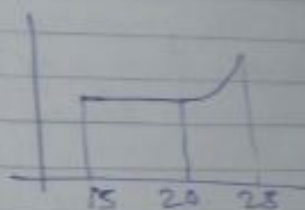
$= \frac{0.2}{0.4} W_{\text{cloud}}$

$dQ = \frac{W_{\text{cloud}}}{2}$

$W > Q$

28- $PV = nRT$

$150 \times 25 =$



$\int P dV$

29-

$P_0 + 2(V^2 + V_0^2 - 2VV_0)$

$P_0 + 2V^2 + 2V_0^2 - 4VV_0 dV$

$P_0 V + \frac{2V^3}{3} + 2V_0^2 V - \frac{2V^2 V_0}{2} \Big|_{20}^{25} = 583.33 \text{ kJ}$

$100 \times 5 + \frac{2(5^3)}{3} + 2 \times 20^2 \times 5 - \frac{2 \times 5^2 \times 20}{2}$

$500 + \frac{2 \times 125}{3} + 4000 - 500$

$P_0 dV = 500 \text{ kJ}$

$40\% \cdot 67$

Total W.D = $500 + 583.33 = 1083.33$

$$Q = m C_v \Delta T \quad PV = mRT$$

$$= 21.71 \text{ J} \times 2 \quad 10^5 \times 2 \times 2500 \times 10^{-6} = m \times 0.287 \times 288$$

$$* = 43.42 \quad m = \frac{2.500 \times 10^{-6} \times 10^5 \times 2}{0.287 \times 288}$$

$$\# P \times 2800 \times 10^{-6} = \frac{2.500 \times 10^{-6} \times 288}{0.287}$$

$$2 \times 10^5 \times 2500 \times 10^{-6} = mR \times 288$$

$$mR = \frac{2 \times 10^5 \times 2500 \times 10^{-6}}{288}$$

$$P \times 2500 \times 10^{-6} = \frac{2 \times 2500 \times 10^{-6} \times 288}{288}$$

$$P_2 = 1.07$$

Steady Flow Energy Equation -

Steady flow means the properties doesn't varies w.r.t. time i.e., mass flow rate at the entry of control volume and at the exit of control volume are same.

Let us assume m is the mass flow rate

u is specific internal energy

pv is flow work

ph is specific enthalpy

KE → specific kinetic energy

PE → " " potential energy

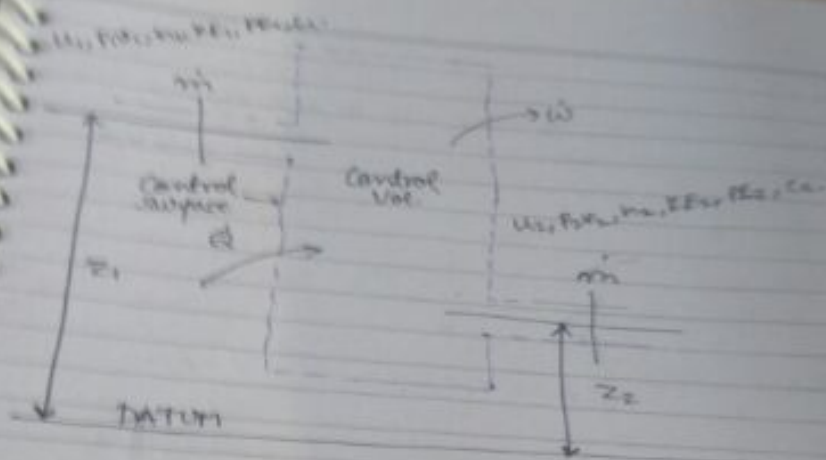
C → velocity

\dot{Q} → Rate of heat input

\dot{W} → Rate of work transfer

Z → Datum height

Subscript 1 & 2 represent inlet & outlet condⁿ resp.



Apply energy conservation -

$$U_1 + P_1 V_1 + KE_1 + PE_1 + Q = U_2 + P_2 V_2 + KE_2 + PE_2 + W$$

$$h_1 + KE_1 + PE_1 + Q = h_2 + KE_2 + PE_2 + W$$

$$\dot{m} \left(C_p T_1 + \frac{1}{2} \frac{C_1^2}{1000} + \frac{g Z_1}{1000} + Q \right) = \left(C_p T_2 + \frac{1}{2} \frac{C_2^2}{1000} + \frac{g Z_2}{1000} + W \right) \dot{m}$$

↳ If units are in kJ,

10^6 if units are in MJ.

if units are in kcal

→ Note: $KE = \frac{1}{2} m C^2$.

$$J = \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$$

$$\boxed{\frac{\text{m}^2}{\text{s}^2} = \frac{J}{\text{kg}}}$$

$$\frac{J}{\text{kg}} \times \frac{\text{kg}}{\text{sec}} \rightarrow \frac{J}{\text{sec}} \rightarrow \text{Watt}$$

Special Cases-

1- Nozzle-

It is a mechanical device of variable cross section used to increase the kinetic energy at the expense of pressure energy.

Assumptions-

(i) Neglecting P.F. changes.

(ii) Well insulated nozzle.

(iii) Zero work.

(iv) Neglecting inlet K.E. energy ^{2m}, if given only then it will apply.

Using energy eqⁿ -

$$h_1 + K.E_1 + P.E_1 + Q = h_2 + K.E_2 + P.E_2 + W$$

$$h_1 = h_2 + K.E_2$$

$$h_1 = h_2 + \frac{1}{2} \frac{C_2^2}{2000}$$

$$\frac{C_2^2}{2000} = h_1 - h_2$$

$$C_2 = \sqrt{2000(h_1 - h_2)}$$

$$C_2 = 44.72 \sqrt{h_1 - h_2}$$

2- Diffuser

It is a mechanical device of variable cross section used to decrease the velocity.

$$C_1 = 44.72 \sqrt{h_1 - h_2}$$

3- Turbine:

It is a work producing device in which energy is transferred from working fluid to rotor. i.e. work is done by the system. In the case of Turbine, expansion of working fluid takes place which results in decrease in pressure.

Assumptions:-

- (i) Neglecting K.E changes.
- (ii) Neglecting P.E changes.
- (iii) Well insulated.

Using SFEE,

$$h_1 + \cancel{K.E_1} + \cancel{P.E_1} + Q = h_2 + \cancel{K.E_2} + \cancel{P.E_2} + W$$

$$\boxed{W = h_1 - h_2} \quad \text{obj.}$$

4- Pump & compressor:-

Both are work absorbing device in which energy is transferred from rotor to the working fluid.

Compressor is generally used to handle the gaseous phase & is used to increase pressure & temp. both. Whereas Pump is generally used to handle the liquid phase & used to increase the pressure of the working fluid.

$$\boxed{W_{p/c} = h_2 - h_1} \quad \text{obj.}$$



5- Boiler & Evaporator -

It is a heat exchanger in which heat is absorbed by the working fluid at constant pressure.

Assumptions -

- (i) Neglecting KE changes.
- (ii) Neglecting PE changes.
- (iii) No work interaction.

EFEE,

$$h_1 + \cancel{5E_1} + \cancel{PE_1} + Q = h_2 + \cancel{PE_2} + \cancel{PE_2} + \cancel{W}$$

$$h_1 + Q = h_2$$

$$\boxed{Q = h_2 - h_1} \quad \text{obj.}$$

6- Condenser -

Heat rejected by the working fluid at constant pressure.

$$\boxed{Q_{\text{cond.}} = h_1 - h_2} \quad \text{obj.}$$

7- Throttling -

Flow through a restricted passage or partially opened valve, porous plug, etc. is known as throttling.

Assumption-

- (i) Neglecting KE changes.
- (ii) Neglecting PE changes.
- (iii) No work interaction.
- (iv) No heat interaction.

SFEE,

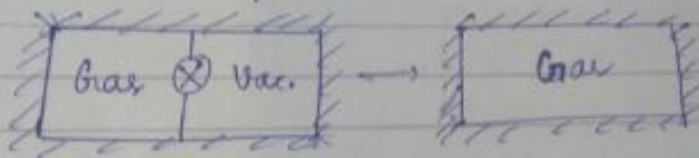
$$h_1 + PE_1 + KE_1 + Q = h_2 + PE_2 + KE_2 + W$$

$$\left[h_1 = h_2 \right]_{\text{adiabatic}}$$

- Note → (i) Throttling is an irreversible adiabatic process.
- (ii) Throttling is also known as constant enthalpy process or isenthalpic process.
- (iii) Throttling always results a decrease in pressure (expansion).

* Free Expansion or (Unrestrained Expansion) -

Expansion against vacuum is known as free expansion.
In the case of free expansion, the value of

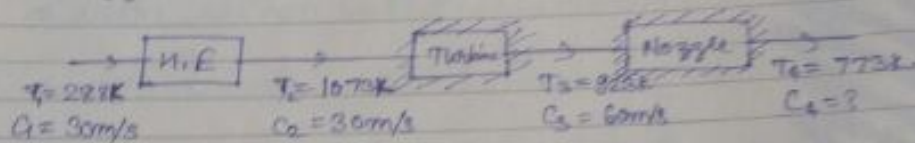


$$\begin{aligned} dQ &= 0 \\ dW &= 0 \\ dQ &= dE + dW \\ dE &= 0, \\ dU &= 0. \end{aligned}$$

→ Free expansion is an irreversible process.

Q- Air at a temperature of 15°C passes through a heat exchanger at a velocity of 30 m/s where the temp. is increased to 300°C . It then enters the turbine with a velocity of 30 m/s and expands until the temp. falls to 650°C . On leaving the turbine the air is taken at a velocity of 60 m/s to a nozzle where it expands until the temp. has fallen to 500°C . If the air flow rate is 2 kg/sec , then calculate-

- Rate of heat transferred to air in the heat exchanger.
- Power output from the turbine, assuming no heat loss in turbine.
- Velocity at the exit of nozzle assuming no heat loss in nozzle.



$$\begin{aligned}
 \text{(i)} \quad h_1 + \cancel{ke_1} + \cancel{pe_1} + q &= h_2 + \cancel{ke_2} + \cancel{pe_2} + \cancel{w} \\
 q &= h_2 - h_1 \\
 &= m C_p (T_2 - T_1) \\
 &= 2 \times 1.005 (1073 - 288) \\
 \boxed{Q &= 1577.85\text{ kJ}}
 \end{aligned}$$

$$\text{(ii)} \quad h_2 + \cancel{ke_2} + \cancel{pe_2} + \cancel{q} = h_3 + \cancel{ke_3} + \cancel{pe_3} + w$$

$$C_p T_2 + \frac{1}{2} \frac{(30)^2}{1000} = C_p T_3 + \frac{1}{2} \frac{(60)^2}{1000} + w$$

$$\begin{aligned}
 w &= 1.005 (1073 - 823) - \frac{1}{2} \frac{(3600 - 900)}{1000} \\
 &= 150.75 - 1.35
 \end{aligned}$$

$$\therefore w = 149.4\text{ kJ/kg}$$

$$P = \dot{m} \times \dot{w}$$

$$= 143.4 \times 2 = 286.8 \text{ kW}$$

$$P = 286.8 \text{ kW}$$

$$\text{iii) } h_3 + KE_3 + PE_3 + Q = h_4 + KE_4 + PE_4 + \dot{w}$$

$$C_p T_3 + \frac{1}{2000} C_3^2 = C_p T_4 + \frac{1}{2000} C_4^2$$


$$\frac{1}{2000} C_4^2 = 1.005 \times 150 + \frac{1}{2000} (60)^2$$

$$= 150.75 + 1.8$$

$$C_4^2 = 305100$$

$$\therefore C_4 = 552.35 \text{ m/s}$$

Workbook

1-  $T = C$
 $dT = 0$
 $dQ = \dot{Q} + d\dot{w}$
 $dQ = d\dot{w}$

2- $h_1 + KE_1 + PE_1 + Q = h_2 + KE_2 + PE_2 + \dot{w}$
 $C_p T_1 + \frac{1}{2000} C_1^2 - 25 = C_p T_2 + \frac{1}{2000} C_2^2$

$$1.005 \times 500 + \frac{1}{2000} (150)^2 = 1.005 \times 510 + \frac{1}{2000} C_2^2$$

a)

$$C_2 = 49 \text{ m/s}$$

Diffuser

22- T=C.

(C)

$$Q = -250 \text{ kcal} = -250 \times 4.187 = -1046.75 \text{ kJ}$$

$$W = -0.53 \text{ kWh} = -0.53 \times 3600 = -1908 \text{ kJ}$$

$$-1908 + (-1046.75) = -2954.75 \text{ kJ}$$

28-



$$V_1 = 15000 \text{ cm}^3$$

$$P_1 = 20 \text{ bar}$$

$$T_1 = 40^\circ\text{C}$$

$$V_2 = 15 \text{ m}^3$$

$$\frac{V_2}{V_1} = \frac{15}{15000} = \frac{1}{1000}$$

Evacuated, Insulated

$$PV = mRT$$

$$20 \times 15 = mR$$

$$312$$

$$PV_2 = \frac{20 \times 15}{1000} \times 312$$

$$P = 0.2 \text{ bar}$$

Unsteady Flow Energy Equation -

Unsteady flow means the properties varies with time i.e., the mass at the entry and exit of control volume are different. Unsteady state problems are solved by using two Conservation principles i.e., mass conservation and Energy conservation.

Let us Assume,

m_1 = Initial mass inside the control volume

m_2 = Final " " "

m_i = Mass at the entry of " "

m_e = " " " exit " "

Apply mass conservation,

$$\frac{E_i}{m_i} \left[\frac{1}{2} \right] \frac{E_e}{m_e} \Rightarrow$$

$$\frac{dm_i}{dt} - \frac{dm_e}{dt} = \frac{dm_{\text{cont.}}}{dt}$$

$$\left[\left(\frac{dm}{dt} \right)_{\text{cont.}} = \dot{m}_i - \dot{m}_e \right] \quad \text{--- (1)}$$

Apply energy conservation,

$$\left[\frac{dE}{dt} = \frac{d}{dt} (\dot{m}_i h_i + \cancel{KE_i} + \cancel{PE_i} + Q) - \frac{d}{dt} (\dot{m}_e h_e + \cancel{KE_e} + \cancel{PE_e} + W) \right] \quad \text{--- (2)}$$

Assumptions -

- (i) Neglecting KE changes.
- (ii) Neglecting PE changes.
- * (iii) Neglecting the variation of enthalpy at inlet and outlet with respect to time.

USFEE -

Applying Assumption ① & ② in eqⁿ (2),

$$\left(\frac{dE}{dt} \right)_{\text{cont.}} = \frac{d}{dt} (\dot{m}_i h_i + \cancel{KE_i} + \cancel{PE_i} + Q) - \frac{d}{dt} (\dot{m}_e h_e + \cancel{KE_e} + \cancel{PE_e} + W)$$

$$\frac{dE}{dt} = \frac{d}{dt} (\cancel{KE} + \cancel{PE} + U) \Rightarrow \frac{dU}{dt} \Rightarrow \text{Internal energy,}$$

$$\left[\frac{dU}{dt} = \frac{d}{dt} (\dot{m}_i h_i + Q) - \frac{d}{dt} (\dot{m}_e h_e + W) \right] \quad \text{--- (3)}$$

$$\frac{dU}{dt} = \dot{m}_i \frac{dh_i}{dt} + h_i \frac{d\dot{m}_i}{dt} + \dot{Q} - \dot{m}_e \frac{dh_e}{dt} - h_e \frac{d\dot{m}_e}{dt} - \dot{W}$$

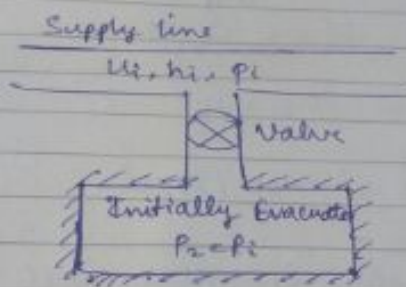
$$= \dot{m}_i h_i + \dot{Q} - \dot{m}_e h_e - \dot{W}$$

$$\left[\frac{dU}{dt} = (\dot{m}_i h_i + \dot{Q}) - (\dot{m}_e h_e + \dot{W}) \right] \quad \text{--- (4)}$$

Applications of Unsteady flow-

- 1- Charging / Discharging of a tank.
- 2- Bottle filling process.

Q.32-



$$\left(\frac{dm}{dt} \right)_{\text{const.}} = \dot{m}_i - \dot{m}_e \quad \text{--- (1)}$$

~~dt~~

$$\left(\frac{dE}{dt} \right)_{\text{const.}} = \frac{d}{dt} (\dot{m}_i h_i + \cancel{KE_i} + \cancel{PE_i} + \cancel{Q}) + \frac{d}{dt} (\dot{m}_e h_e + \cancel{KE_e} + \cancel{PE_e} + \cancel{W}) \quad \text{--- (2)}$$

Assume,

- | | |
|-------------------------|-------------------|
| ① $\Delta KE = 0$ | ⑤ $\dot{m}_i = 0$ |
| ② $\Delta PE = 0$ | ⑥ $\dot{Q} = 0$ |
| ③ $\frac{dh_i}{dt} = 0$ | ⑦ $\dot{W} = 0$ |
| | ⑧ $\dot{m}_e = 0$ |
| ④ $\frac{dh_e}{dt} = 0$ | |

$$\left(\frac{dU}{dt}\right)_{\text{cont}} = \frac{d(mu)}{dt}$$

$$= m \frac{du}{dt} + u \frac{dm}{dt}$$

$$\left[\left(\frac{dU}{dt}\right)_{\text{cont}} = \dot{m} h_i\right] \quad \text{--- (1)}$$

$$\text{eqn (1) becomes } \left[\left(\frac{dm}{dt}\right)_{\text{cont}} = \dot{m}_i\right] \quad \text{--- (2)}$$

Use eqn (2) in (1),

$$\left(\frac{dU}{dt}\right)_{\text{cont}} = \left(\frac{dm}{dt}\right)_{\text{cont}} h_i$$

$$U_2 - U_1 = (\dot{m}_2 - \dot{m}_1) h_i$$

$$U = \frac{U}{m}$$

$$\boxed{U = u m}$$

$$\dot{m}_2 u - \dot{m}_1 u = (\dot{m}_2 - \dot{m}_1) h_i$$

$$\dot{m}_1 = 0$$

$$\dot{m}_2 u = \dot{m}_2 h_i$$

$$\boxed{u_2 = h_i}$$

Hence Proved.

→ Note - If the working fluid is ideal gas, then final temp. inside the tank is 'r' times the temp. of supply lines.

$$u_2 = u_1$$

$$C_v T_2 = C_p T_1$$

$$T_2 = \frac{C_p}{C_v} T_1$$

$$\boxed{T_2 = r T_1}$$

Answers -

23- (C)

24- $W = -260 \text{ W}$, $Q = 10 \text{ W}$.

(b) $dQ = dU + dW$

$$dU = dQ - dW = -10 + 260 = 250 \text{ W}$$

$$dU = \frac{250 \times 3600}{1000} = 900 \text{ kJ}$$