- Dimensions and Units :-

Dimension	Unit
1. Length	meter (m)
2. mass	kilogram (kg)
3. Time	Second (s)
4. Temperature	Kelvin (K)
5. Electric current	Ampere (A)
6. Amount of Light	Candela (c)
7. Amount of matter	mole (mol)

Quantity	SI Units	From English to SI Units
Area	m^2	1 ft = 0.3048 m
Density	kg/m^3	1 in = 0.0254 m
Energy	J	1 lb_m = 0.4536 kg
		1 Slug = 14.594 kg
Force	N	1 lb_f = 4.448 N
Heat flux	W/m^2	
Heat transfer rate	W	1 Btu = 1055.06 J
		1 Cal = 4.1868 J
		1 Btu/lb_m = 2326 J/kg

Quantity	SI Units	from English to SI Unit
mass flow rate	kg/s	
Power	W (J/s)	1 hp = 745.7 W
Pressure & Stress	N/m^2	1 lb_f/ft^2 = 47.88 N/m^2 1 psi = 1 lb_f/in^2 = 6894.8 $\frac{N}{m^2}$
Specific heat	J/kg.K	
Surface tension	N/m	
Velocity	m/s	
Viscosity	m^2/s	
Volume	m^3	
Volume flow rate	m^3/s	
Specific volume	m^3/kg	

1 Standard atmospheric pressure = $1.01325 \times 10^5 \ \frac{N}{m^2}$

1 N/m^2 = 1 Paskal = 1 Pa

1 gal = 0.003785 m^3

- Thermodynamics :-

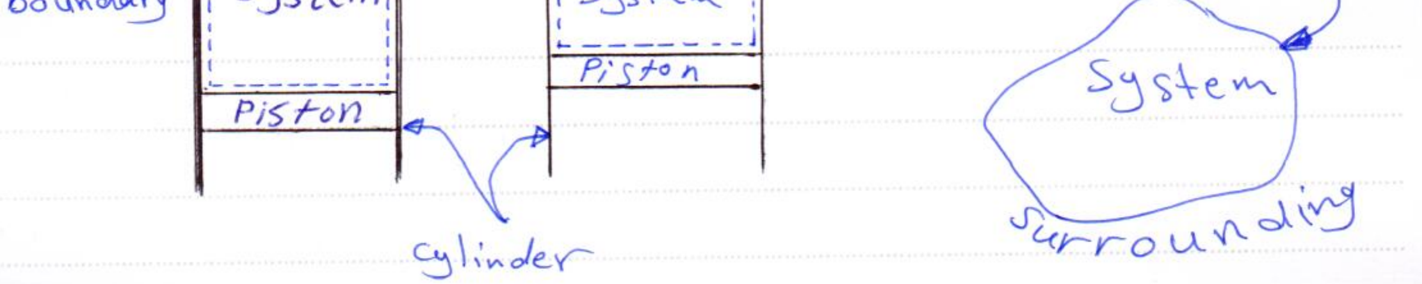
Thermodynamic is an axiomatic science which deals with the relations among heat & Work and Properties of system which are in equilibrium. It described state and changes in state of Physical system.

— System :-

A system is a finite quantity of matter.

— Boundary :-

The actual envelope enclosing the system is the boundary of the System. The boundary may be fixed or it may move. The boundary may be real or imaginary.



— Working Substance :-

The working substances are in general fluids which are capable of deformation in that they can readily be expanded and compressed. Common examples of working substances used in thermodynamic system air and steam.

— Pure Substance :-

Is a single substance or mixture of substance which has the same consistent composition throughout such as water, Nitrogen, Heli-

— Heat , Work :-

Heat is a form of energy which is transferred from one body to another body at lower temperature by virture of the temperature difference between the bodies. The symbol of heat is "Q" .

Work is defined as the product of the force (F) and the distance moved (x) in the direction of the force.

Work = Force × distance

Note: The heat and work are transient quantites not properties.

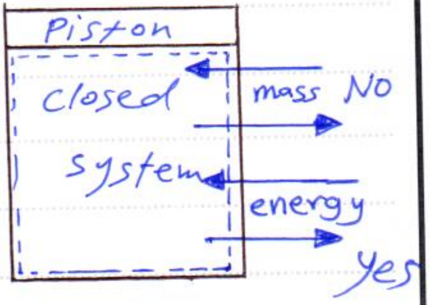
- Closed and Open system:-

A system may be considered to be closed or open depending on whether a fixed mass or a fixed Volume in space is chosen for study.

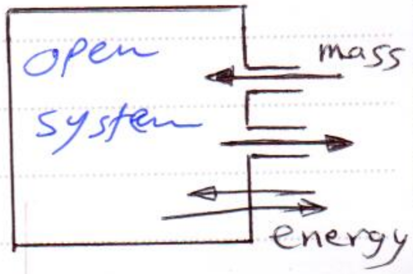
A closed system consist of a fixed amount of mass and no mass Can across its boundary, that is no mass Can enter or leave a closed system.

But energy in the form of heat or work can cross the boundary. and the Volume of a closed system does not have to be fixed.

If as a special Case, even energy is not allowed to cross boundary, that system is Called an Isolated system.



An Open system, It involves mass flow, such as a Compressor, turbine or nozzle. Both mass and energy Can cross the boundary.



Adiabatic System :- $(Q = 0)$

Is one which is thermally insulated from its surrounding, it can exchange work with its surrounding.

- Properties of a System :-

Any characteristic of a system is called a property. Some familiar examples are pressure (P), temperature (T), volume (V) and mass (m).

Note all properties are independent, some are defined in terms of other ones. such as density ρ, specific volume v, specific gravity ρ_s.

Properties are considered to be either intensive or extensive.

Intensive properties are those that are independent of size of a system, such as temperature, pressure and density.

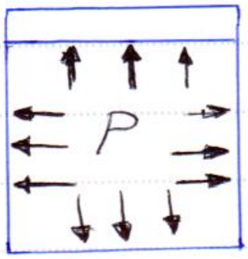
Extensive properties are those whose values depend on the size or extent of the system, such as mass, volume, and total energy.

- Pressure :-

Pressure is defined as a force per unit area.

has the unit of Newtons per square meter (N/m^2) which called a pascal (Pa).

$$\boxed{P = F/A}$$



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

$1 \text{ P}_{atm.} = 1.01325 \times 10^2 \text{ kPa} = 1.01325 \text{ bars}.$

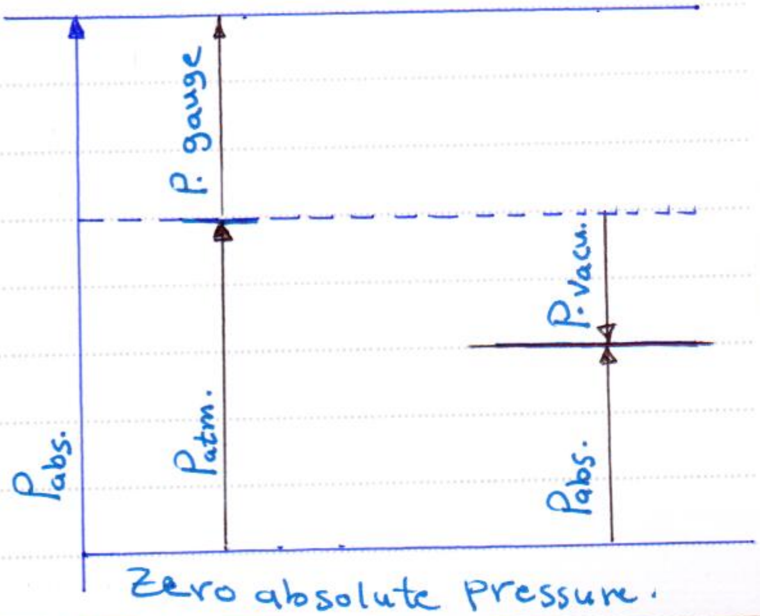
$1 \text{ atm} = 14.696 \text{ psi} = 760 \text{ mm Hg}.$

The difference between the absolute pressure and the local atmospheric pressure is called gauge pressure.

Pressure below atmospheric pressure are called vacuum pressure.

$P_{gauge} = P_{abs.} - P_{atm.}$

$P_{vacu.} = P_{atm.} - P_{abs.}$



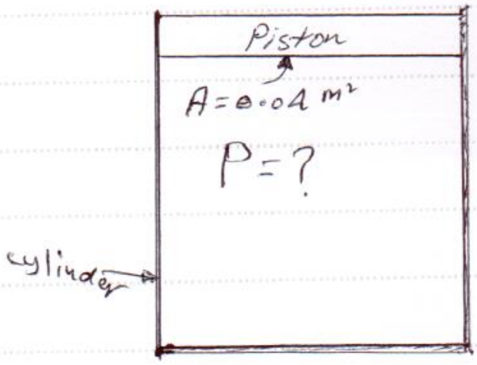
Example :- A vacuum gage connected to a chamber reads 5.8 Psi at location where the atmospheric Pressure is 14.5 Psi. Determine the absolute pressure in the chamber.

Sol.

$$P_{abs.} = P_{atm.} - P_{vac.} = 14.5 - 5.8 = 8.7 \text{ Psi.}$$

Example :- The piston of a piston-cylinder device containing a gas has mass of 60 kg and a cross-section area of 0.04 m² as shown below. The local atmospheric Pressure is 0.97 bar and the gravitational acceleration is 9.81 m/s². a) Determine the pressure inside the cylinder.

Sol.



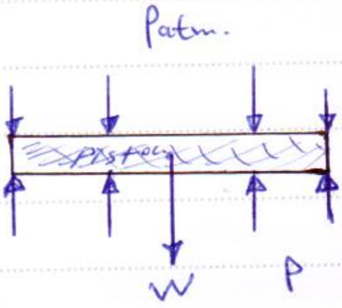
Equilibrium $\Rightarrow \Sigma F = 0$

$$P * A = P_{atm.} * A + W$$

$$P = P_{atm} + \frac{W}{A} = P_{atm} + \frac{m \cdot g}{A}$$

$$= 0.97 + \frac{60 * 9.81}{0.04} = 1.117 \text{ bars.}$$

b) If some heat is transferred to the gas and its volume doubles, do you expect the pressure inside the cylinder to change



- Temperature :-

The temperature is define as measure of hotness.

- Temperature Scales :-

The temperateure scales used in the SI Units and in English Units system are the celsius scale « Centigrade Scale » and the «Fahernheit Scale».

The temperature Scales were based on two fixed Points

i - The Steam Point « Boiling Point » of the water at standard atmospheric Pressure.

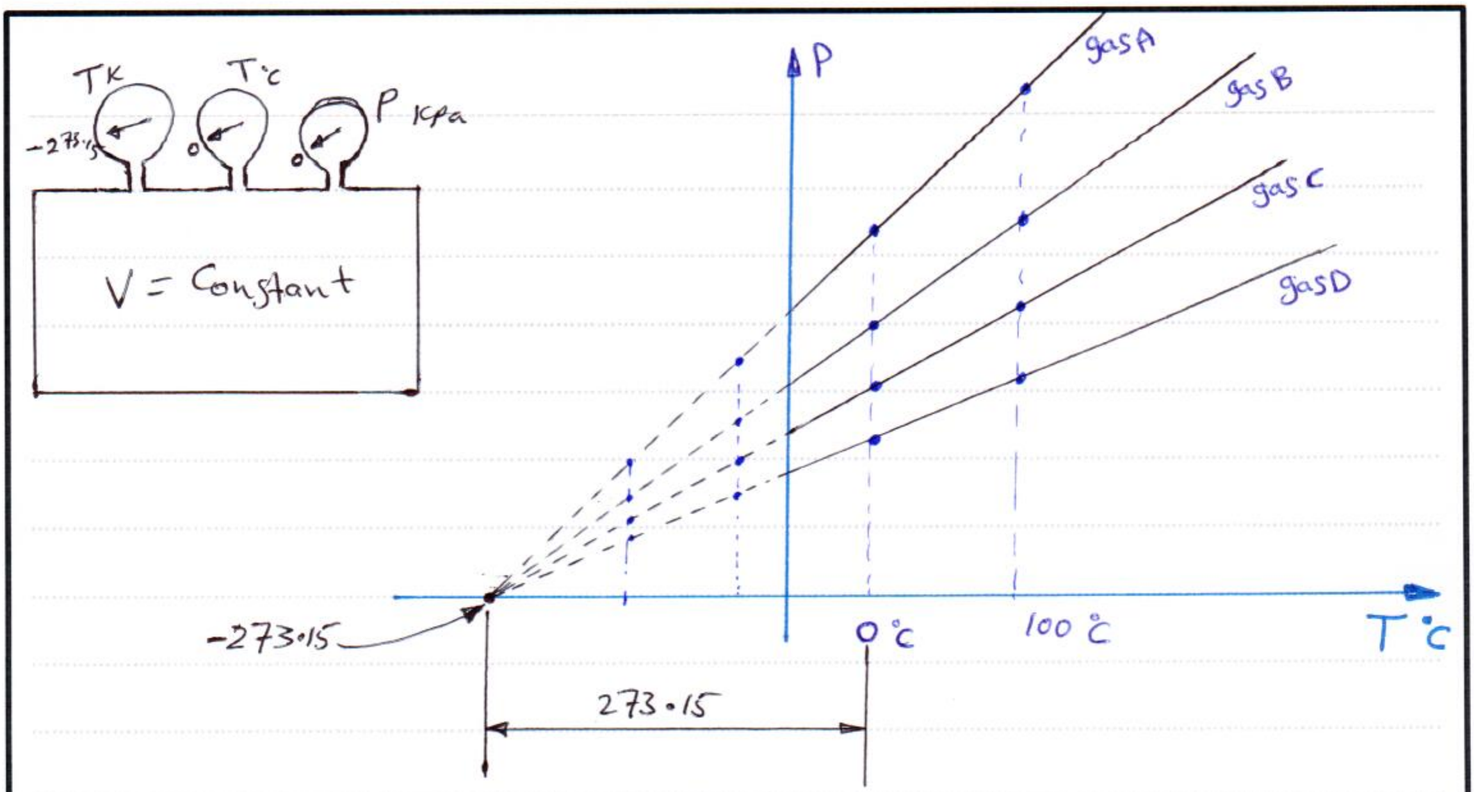
ii - The ice Point « freezing point » of the water.

The fixed Points for these temperature scales are

Temperature	Celsius Scale	Fahernhiet scale
Steam Point	100	212
Ice Point	0	32
Interval	100	180

$$^{\circ}C = \frac{5}{9}(F - 32)$$

$$K = {}^{\circ}C + 273 \quad ; \quad R = 1.8 * K = F + 460$$



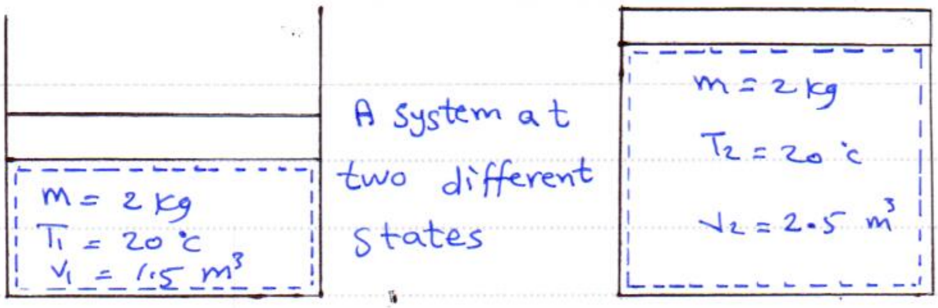
The temperature scale in thermodynamic, In SI Units System called Kelvin Scale (K) and in English System is the Rankine (R).

[Pressure Versus Temperature at experimental data obtained from a Constant Volume gas thermometer using four different gases at different Pressure].

$$T_{(K)} = T_{(°C)} + 273.15$$

- State and Equilibrium :-

Consider a system that is not undergoing change. At this point all Properties can be measured or Calculated throughout the entire system, which gives as a set of properties that completely describe the Condition, or the state of the System.



A system at two different states

a. State 1 b. State 2

thermodynamics deals with equilibrium states. The word Equilibrium implies a state of balance.

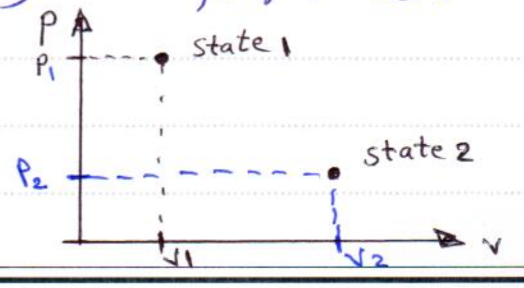
- Types of Equilibrium.

1. Thermal equilibrium:- The temperature of the system does not change with time and has same value at all points of the system.

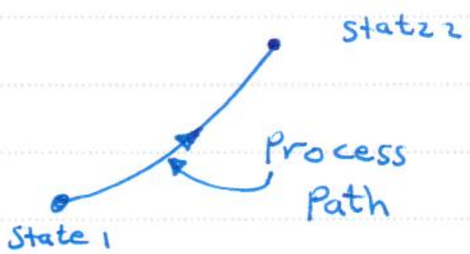
2. Chemical equilibrium:- No chemical reaction take place in the system and the chemical composition which is same throughout the system does not vary with time.

- Processes and cycles:-

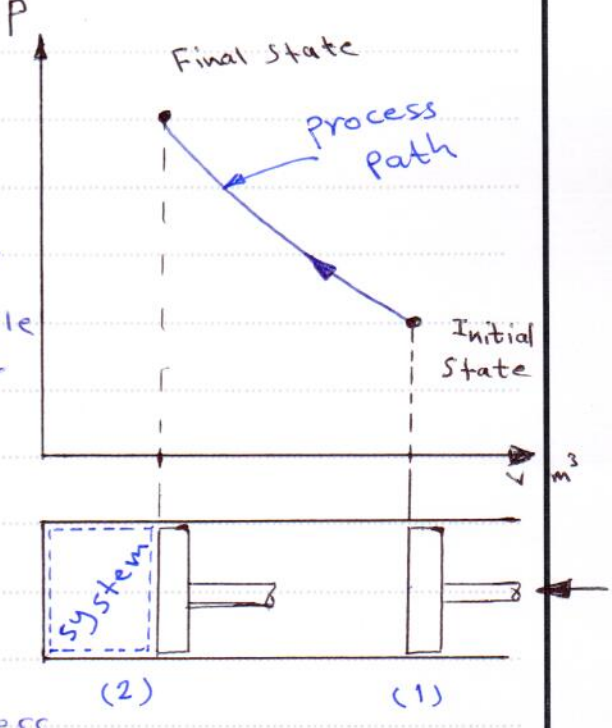
* State:- It's the condition of the system at an instant of time described by it's properties.



Any change that a system undergoes from one equilibrium state to another is called a Process, and the series of states through which a system passes during a process is called the path of the process.



Some common properties that are used as coordinates are temperature T, Pressure P, and Volume V, or specific volume v.



The prefix iso- is often used to designate a process for which a particular property remains constant.

An isothermal process, for example is a process during which the temp. T remains constant.

An isobaric process is a process during which the Pressure P remains constant.

An isochoric (or isometric) process is a process during which the specific volume v remains constant.

- Types of thermal Cycle :-

1- Thermodynamic Cycles:

In this cycle no change in the chemical structure and the Properties of fluid for example the Steam in power plant.

2- Mechanical Cycles:

In this cycle the properties of fluid or Substance will be Change for example the Internal-Combustion Engine

- Energy :-

Energy is defined as that capacity a body or Substance possesses which can result in the Performance of Work. From the Law of Conservation of energy the energy Cannot be relativelly Created or destroyed.

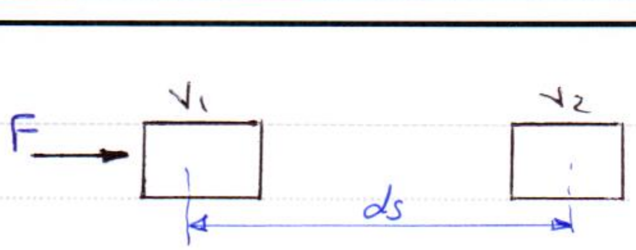
- Forms of Energy :-

Energy Can exist in numerous forms such as thermal, mechanical, Kinetic, Potential, electric, Chemical, and their Sum Constitutes the total energy E of a system.

1. Kinetic energy:- The energy that a system Possesses as a result of its motion relative to reference is called Kinetic Energy ((K.E.))

$dE = F \cdot ds$

$F = m \cdot a = m * \frac{dv}{dt}$



V: velocity , t: time

$\therefore dE = m \frac{dv}{dt} * ds = m \frac{ds}{dt} \cdot dv \quad , \frac{ds}{dt} = V$

$\therefore \int dE = \int m * V\, dv \Rightarrow \int_0^E dE = m \int_{V_1}^{V_2} V\, dv$

$\therefore E = m \frac{V^2}{2} \Big|_{V_1}^{V_2} = \frac{1}{2} m (V_2^2 - V_1^2) \quad , \text{if } V_1 = 0$

$\therefore \boxed{K.E = \frac{1}{2} m V_2^2}$ kJ

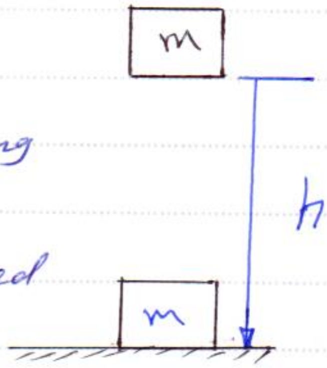
or for unit mass « specific k.E » $k.e = \frac{1}{2} V^2$ kJ/kg

2. The energy that a system possesses as a result of its elevation in a gravitational field is called Potential Energy P.E and is expressed as:

$P.E = W * h = m * g * h$ «J» (N.m)

g: gravitational acceleration

h: elevation



Any volume of fluid entering or leaving a system displace an equal volume, the energy produced due to this flow is called Flow energy $FE = P.V$

3- Heat Energy :-

It is one form of energy produced when Temperature difference between the system and Surrounding. The symbol is "Q"

4- Work Energy :-

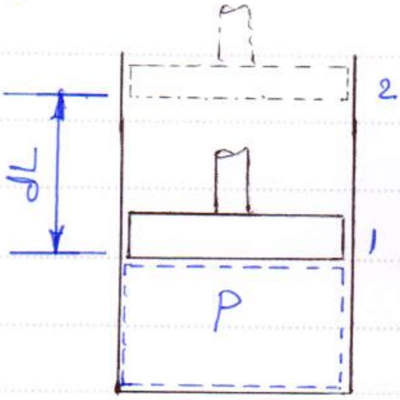
It is a form of energy defined as the multiplication of the force effected on the mass by the distance that the mass will be moved due to thi effect.

$$dw = F * dL = P \cdot A\, dL \quad , \quad dv = A\, dL$$

$$dw = P * dv$$

$$\therefore \int_1^2 dw = \int_{v_1}^{v_2} P\, dv \Rightarrow$$

$$\boxed{W_{1-2} = \int_{v_1}^{v_2} P * dv} \quad kJ$$



Power: Is the rate of doing work

$$P = \frac{W}{t} \quad J/s \text{ "Watt"}$$

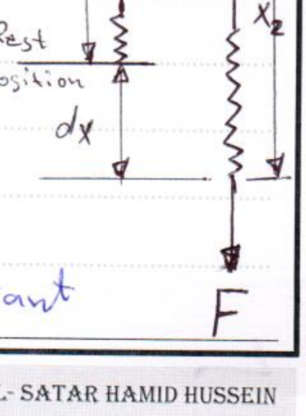
$$P = w * \dot{m} \quad , \quad \dot{m} = \text{flow rate} = \rho V A$$

- Spring Work:

$$dw = F * dx \quad , \quad F = K * X$$

$$\int dw = \int_{x_1}^{x_2} k\, x\, dx \Rightarrow W = k \int_{x_1}^{x_2} x dx = \frac{k}{2}(x_2^2 - x_1^2)$$

$$W_{spring} = \frac{1}{2} k (X_2^2 - X_1^2) \quad ; \quad K: \text{Spring Constant}$$



The total energy of a system in two groups :-

1. Microscopic 2. Macroscopic

5- The microscopic forms of energy are those related to the molecular structure of a system. The sum of the microscopic forms of energy is called the (Internal Energy) of a system and is denoted by (U).

Ex. : An insulated 2 kg box falls from a ballon 3.5 km above the earth. what's the change in potential energy of the box after it has hit the earth surface.

Sol. : $P.E = m.g\,h = 2 \times 9.81 \times 3500 = 6867 \text{ J}$

Ex. : A force (F) is proportional to (x^2) and has the value of 133 N when $x=2$, Determine the work done by it moves in object from $x=1$ to $x=4$ where (x) in meter.

Sol. : $W = \int_{x_1}^{x_2} F \cdot dx = \int_1^4 k x^2 dx = k_1 \int_1^4 x^2 dx$

$F \propto x^2$

$F = k\,x^2$

$$w = k\left[\frac{x^3}{3}\right]_1^4 = \frac{133}{4*3}\left[4^3 - 1^3\right] = 69825 \text{ N.m}$$

$F = k\,x^2$

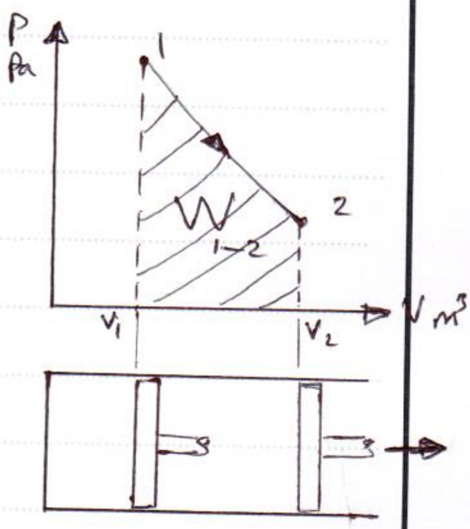
$133 = k * (2)^2$

$\boxed{k = \frac{133}{4}}$

Ex.: Let the Pressure in the cylinder in the fig. given by the equation $P = C/V$ as a function of Volume.

a) find the work done, if the initial pressure is 400 kPa the initial Volume $0.02\ m^3$ and the final Volume is $0.08\ m^3$

b) Is the sign correct?



Sol.:-

a) $P = \frac{C}{V} \Rightarrow PV = C$

$\therefore P_1V_1 = P_2V_2 = \text{Constant}$

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

$$= C\int_{V_1}^{V_2} \frac{dV}{V} = P_1V_1 \int_{V_1}^{V_2} \frac{dV}{V}$$

$$W = P_1V_1 \ell \frac{V_2}{V_1} = 400 \times 0.002 \times \ln\left(\frac{0.08}{0.02}\right) = 11.09\ kJ$$

b) the Sign correct Since it is positive and the work is done by the system.

Ex.: The pressure in the cylinder as shown varies the following manner with Volume $P = C/V^2$, if the initial Volume is $0.05\ m^3$ and the final Pressure 200 kPa find the work done by the system. the initial Pressure is 500 kPa.

- Reversibility :-

A more rigorous definition of reversibility is follows :

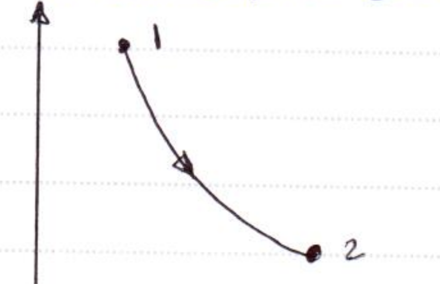
When a fluid undergoes a reversible process, both fluid and its surrounding can be restored to their original state.

The criteria of reversibility are as follows:-

1- The Process must be frictionless.
2- The difference in Pressure between the fluid and its surrounding during the Process must be infinitely small.
3- The difference in temperature between the fluid and its surrounding during the Process must be infinitely small.

A reversible process between two states drawn a line on diagram of properties.

An irreversible process is represented by a dotted line joining the end states to indicate the intermediate states are indeterminate.



reversible Process

irreversible Process

- Internal reversibility :

It is may be obtained, because no process in practice is truly reversible, but with conditions below :-

1. The Surrounding Can never be restored to their original state. and the path of the Process
2. The fluid itself is at all times in an equilibrium state and the path of the Process can be exactly retraced to the initial State.

Reversibility or Reversible Process

هي العملية التي يعود فيها النظام إلى حالته الاصلية. فإذا اجري اجراء ما على النظام، ثم اوقف هذا الاجراء وعكس اتجاهه بحيث عادت كميات الشغل والحرارة إلى النظام والمحيط كل إلى مصدره الاصلي. فان هذا الاجراء انعكاسي.

فمثلا نتصور تمدد المائع ادياباتيا في توربين، ثم يضغط في ضاغط، فإذا تم ذلك بحيث يعود المائع إلى حالته الميكانيكية والثرموديناميكية الاصلية، وبحيث يكون الشغل الناتج عن التوربين كافيا لتشغيل الضاغط؛ عندئذ يكون التمدد في التوربين محققا لفكرة الاجراء الانعكاسي. وبنفس الطريقة من التمدد نظريا أن يعاد المائع المار في منفث إلى حالته الابتدائية اذا حررناه في ناشر من دون تأثير في المحيط.

ان معظم العمليات الحقيقية تتم داخل نظام يتألف من مكبس واسطوانة، كمكائن الاحتراق الداخلي الترددية، الضواغط الغازية ... الخ. ولغرض التبسيط نفترض ان العمليات فيها انعكاسية. التي يمكن الحصول عليها بدفع المكبس ببطء جداً لتجنب الاضطراب وكي يكون هناك وقت كافٍ ليصبح الضغط ودرجة الحرارة متساوياً في جميع النقاط.

العملية الانعكاسية مثالية افتراضية، أي لا توجد في العمليات الطبيعية أو الدورات الحقيقية. ولكن يمكن التقرب من هذه العمليات عند توفر الشروط الافتراضية التالية:

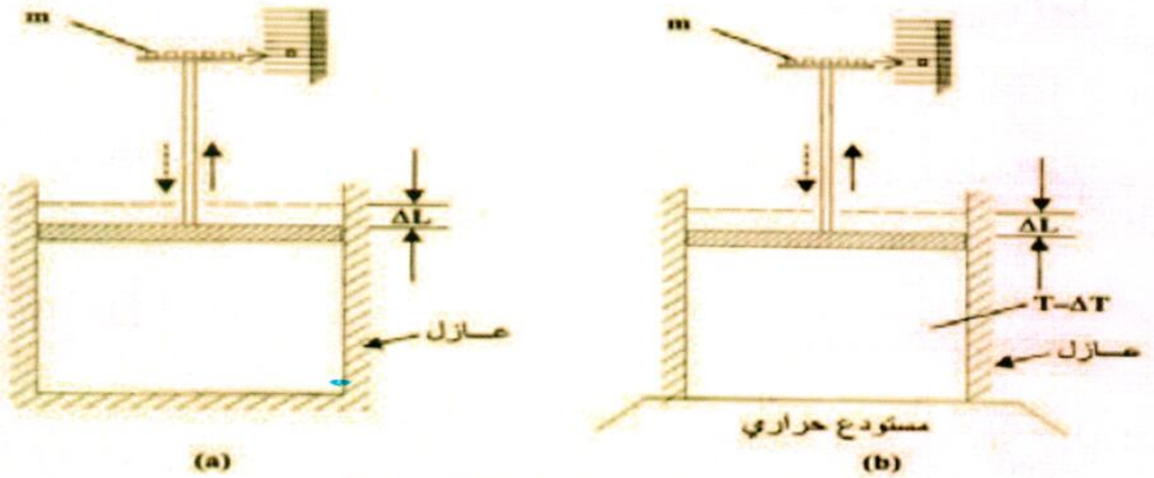
1. **أن تكون العملية بطيئة. وهذا يؤدي إلى:**
   - أ. انعدام الاحتكاك الميكانيكي والمائعي.
   - ب. تساوي القوى المؤثرة على المكبس.
   - جـ ..انعدام الفقدان الحراري.
2. **ان تكون العملية متزنة حراريا. وهذا يؤدي إلى:**
   - أ. تساوي ضغط ودرجة حرار النظام والمحيط.
   - ب. انتقال الشغل والحرارة من وإلى النظام متساوي في الاتجاهين.

فمثلا في عملية تمدد الغاز ضمن اسطوانة مجهزة بمكبس، يوجد مقدار قليل من الاحتكاك وفرق قليل في ضغط ودرجة حرارة النظام والمحيط بحيث يمكن اهمالها. أي أن المكبس في هذه الحالة يكون عديم الوزن والاحتكاك والتسرب. وبالتالي يمكن حساب الشغل على اساس أن التمدد انعكاسي.

الاجراء الانعكاسي Irreversible Process

هي العملية التي تحدث بإتجاه واحد ولا يمكن عكسها. أي لا يمكن أن يعود النظـام إلـى حالتـه الاصلية تلقائيا أو دون تأثير خارجي، بسبب وجود الاحتكاك وانعدام الاتزان الحراري.

ولمناقشة هذه العملية نفترض وجود اسطوانة معزولة تحتوي على غاز مغلق بمكبس معزول فوقه اثقال، ونفترض ايضا أن المكبس يلتصق كثيراً بجدران الاسطوانة.



(a) (b)

الانعكاسية واللاانعكاسية

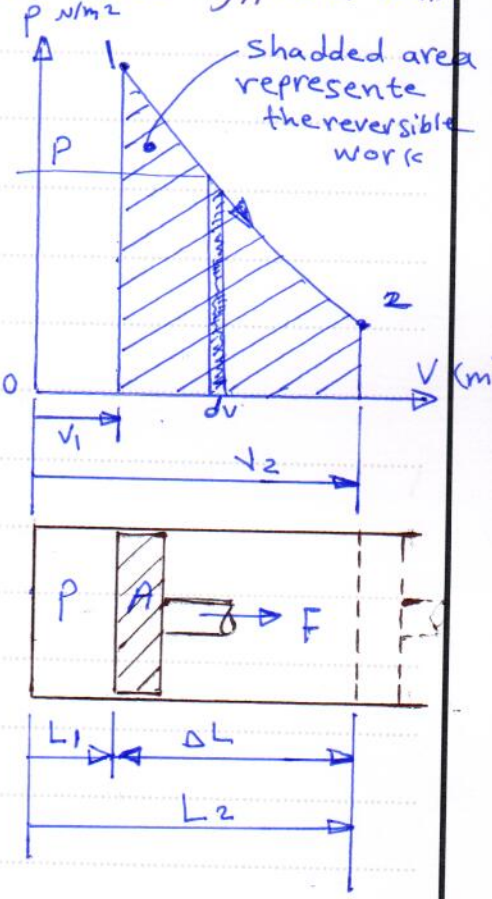
عند إزالة ثقل من هذه الاثقال فسيتحرك المكبس مسافة (ΔL) حاملا معه بقية الاثقال. أي أن النظام ينجز شغلا على الخليط. وأثناء هذه العملية يتسارع المكبس في البداية ثم يتباطأ تدريجيا حتى يصل إلى الحالة النهائية. وقد يتذبذب المكبس بين الحالتين ولكن هذه الحركة التذبذبية تخمد بالتدريج نتيجة للاحتكاك الميكانيكي والمائعي.

هذه التأثيرات تمنع وصول المكبس إلى الارتفاع الذي يمكن الوصول إليه في غيابها، لـذلك يقـل الشغل المنجز. هذه العملية لا انعكاسية لأنها مصحوبة بمفقودات حرارية جـراء الاحتكـاك. وتبقـى العملية لا انعكاسية حتى في حالة انعدام الاحتكاك الميكانيكي وبقاء الاحتكاك المائعي. وبمـا أن هـذه الظواهر موجودة دائما لذا فأن الاجراءات الحقيقية لا يمكن أن تكون انعكاسية.

- Reversible work :-

Consider an ideal frictionless fluid contained in a cylinder behind a piston, with the following assumptions :-

1. the Pressure and temperature of the fluid are Uniform.
2. no friction between the Piston and the cylinder wall.



work done by fluid = $F * dL$

$F = P * A \Rightarrow W = P * A * dL = P dV$

Per unit mass

$W = P\,dv$

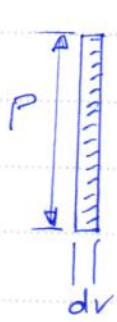
where (v) is the specific volume

$dw = F * dL$

$F = P * A$

P: Pressure in the cylinder

A: Cross-section area of the Piston.



The reversible work = the area under the curve on (P-V) diagram.

$dw = P * A * dL \quad ; \quad A * dL = dV$

$\therefore dw = P * dV \Longrightarrow W = \int_{V_1}^{V_2} P * dV = P(V_2 - V_1)$

Note: Irreversible work $\neq \int_{V_1}^{V_2} P\,dV$.

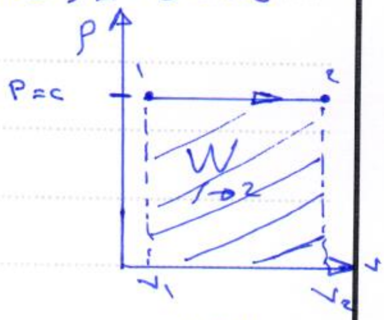
Ex. A certain fluid at 10 bars is contained in a cylinder behind a piston, the initial volume being 0.05 m³. Calculate the work done by the fluid when it expands reversibly.

a- at constant pressure to final volume of 0.2 m³.

Sol.

$$\text{Reversible work} = \int_{v_1}^{v_2} P * dv$$

$$\therefore W = \int_{0.05}^{0.2} 10*10^2 \, dV = 10^3 * (0.2 - 0.05) = 150 \text{ kJ}$$

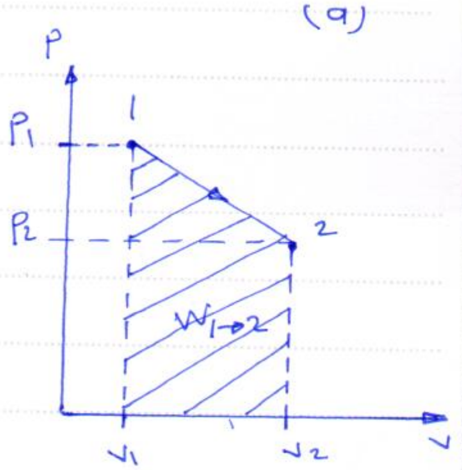


(a)

b- According to a linear law to a final volume of 0.2 m³ and final pressure of 2 bars.

$$* \text{ linear law} = \frac{P - P_1}{V - V_1} = \frac{P_2 - P_1}{V_2 - V_1}$$

$$\frac{P - 10*10^2}{V - 0.05} = \frac{2*10^2 - 10*10^2}{0.2 - 0.05}$$



$$0.15 P + 800V - 190 = 0$$

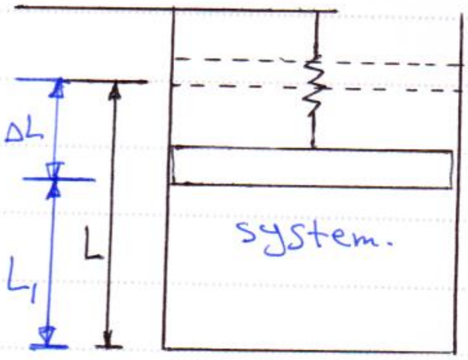
$$\therefore P = \frac{190 - 800V}{0.15}$$

$$W = \int_{v_1}^{v_2} P * dv = \int_{0.05}^{0.2} \left(\frac{190 - 800V}{0.15}\right) dV = \frac{1}{0.15} \left(190V - 400V^2\right]_{0.05}^{0.2}$$

$$\therefore W = 90 \text{ kJ}$$

Ex.: Consider the system shown in fig., the initial Volume inside the cylinder is $0.1\ m^3$. At this state the pressure inside is 100 kpa. which just balance the atmosphere pressure plus the Piston weight, the spring is touching but exerts no force on the Piston at this state. The gas now heated until the Volume is doubled. The final Pressure of the gas is 300 kpa and during the Process the spring force is proportional to the displacement of the Piston from the initial position. Calculate the work done by the system.

Sol.:-



$P_1 = 100\ kpa\ ,\ V_1 = 0.1\ m^3$

$P_2 = 300\ kpa\ ,\ V_2 = 0.2\ m^3$

$F \propto \Delta L\ ,\quad \Delta L = L - L_1$

$F_s \propto (L - L_1)$

$(F_s/A) \propto (L - L_1)/A$

$P_s \propto \frac{(L-L_1)A}{A^2} \Rightarrow P_s \propto \frac{V-V_1}{A^2}$

$$P_s = \frac{C}{A^2}(V - V_1) = a(V - V_1)$$

$P_t = P_o + P_s = 10^2 + a(V_2 - V_1) \Rightarrow 300 = 10^2 + a(0.2 - 0.1) \Rightarrow a = 2000$

$P_t = 10^2 + 2000(V - 0.1) = 2000V - 100 \Rightarrow W = \int_1^2 P\,dV = \int (2000V - 10^2)\,dV$

$W_{1\text{-}2} = \left[\frac{2000V^2}{2} - 10^2 V\right]_{0.1}^{0.2} = 20\ kJ.$

If there is no spring the Piston will rise at constant pressure.

$W = \int_1^2 P\,dV = P\int_1^2 dV = P(V_2 - V_1) = 10^2(0.2 - 0.1) = 10\ kJ$

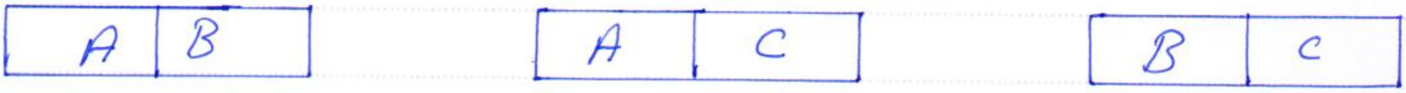
c - According to Law $PV = C$ to final volume of 0.1 m^3.

d - According to Law $PV^3 = C$ to a final Volume of 0.06 m^3

e - According to Law $P = (a/V^2) - (b/V)$ to a final volume of 0.1 m^3 and final Pressure of 1 bar. (a & b) are constant.

- The Zeroth Law :-

This Law is concerned with thermal equilibrium. It states that if two bodies are separately in thermal equilibrium with a third body then they must be in thermal equilibrium with each other.



thermal equili. thermal equili. thermal equili.

If $T_A = T_B$, $T_A = T_C \Rightarrow \therefore T_B = T_C$ (thermal equilibrium).

- The first Law of thermodynamics :-

" When a system undergoes a thermodynamic cycle then the net heat supplied to the system from its surrounding is equal to the net work done by the system on its surrounding.

$$\oint dQ = \oint dW$$

Where $\oint$ represents the Sum for a complete cycle.

Ex.: $1.5\ \frac{kg}{s}$ Steam flow rate in a steam power plant where the turbine develops $10^3\ \frac{kJ}{s}$; the heat rejected by the system to cooling water in the condenser is 2100 kJ/kg and the feed pump work required to pump the condensate back into the boiler is 5 kw, calculate the heat supplied to the steam in the boiler.

Sol.

$$\sum dQ = \sum dW$$

$$\sum dW = 10^3 - 5 = 995\ kW$$

$$Q = \dot{m} * q$$

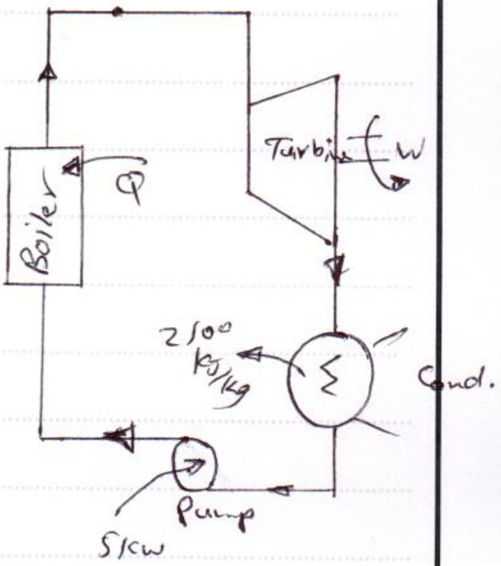
from first law of thermo.

~~1.5~~ $* \sum Q = \sum W$

$$\sum \dot{m} q = \sum W$$

$$1.5 * q = 995$$

$$\therefore q =$$

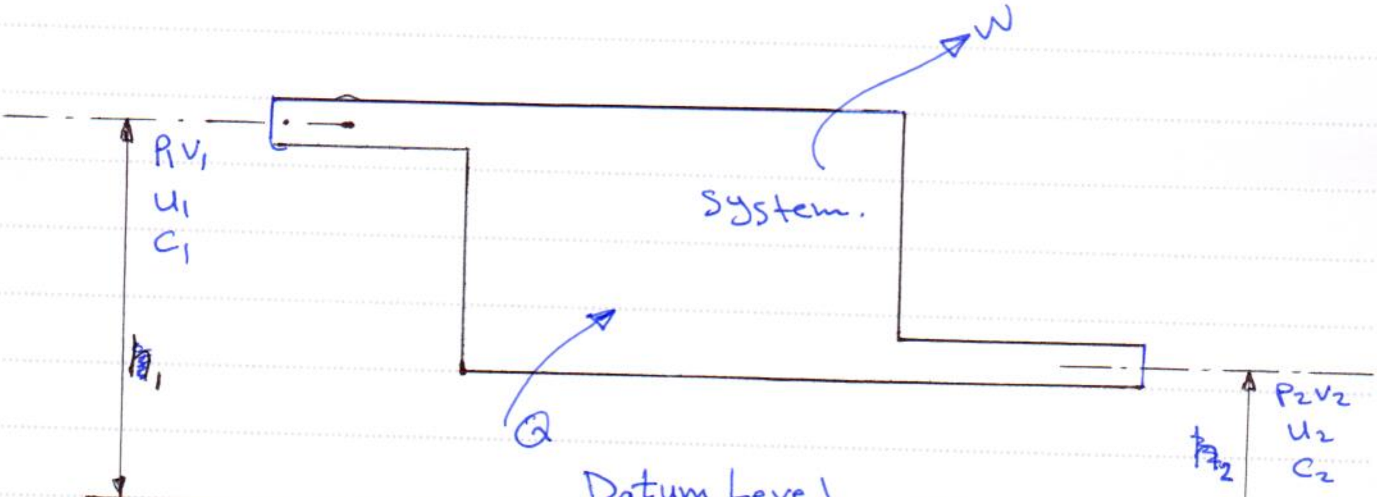


- The Steady flow energy equation :- (SFEE).

This equation is a mathematical statement of Principle of conservation of energy as applied to the flow of a fluid through a thermodynamic system.

The various forms of energy which the fluid can have are as follows :-

1. Potential energy : $P.E = mgh$ kJ
2. Kinetic energy : $K.E = \frac{1}{2} m c^2$ kJ
3. Internal energy : $U = m.u$ kJ
4. Flow or displacement energy : $F.E = P.V$ kJ
5. Heat received or rejected : Q
6. External work done : W



Applying the Principle of conservation of energy to the system, then.

Total energy entering the system = Total energy leaving the system.

$$E_{input} = E_{output}$$

$$P.E_1 + I.E_1 + F.E_1 + K.E_1 + Q = P.E_2 + I.E_2 + F.E_2 + K.E_2 + W$$

for 1 kg of fluid:

$$gz_1 + u_1 + P_1 v_1 + \frac{1}{2} c_1^2 + q = gz_2 + u_2 + P_2 v_2 + \frac{1}{2} c_2^2 + w$$

$$gz_1 + (u_1 + P_1 v_1) + \frac{1}{2} c_1^2 + q = gz_2 + (u_2 + P_2 v_2) + \frac{1}{2} c_2^2 + w.$$

$u_1 + P_1 v_1 = h_1$ The enthalpy ; $u_2 + P_2 v_2 = h_2$

$$\boxed{gz_1 + h_1 + \frac{1}{2} c_1^2 + q = gz_2 + h_2 + \frac{1}{2} c_2^2 + w}$$

Steady - Flow Energy Equation (SFEE)

where q & w per unit mass

Mass flow rate: $\dot{m} = \rho c A = \frac{cA}{v}$.

- The non-flow energy equation: (NFEE)

In the case of a closed system, however in which the fluid mass remains constant, no substance passing through the system boundary, the flow terms in study flow E.E. will not apply. Thus the terms Pv and $c^2/2$ are neglected. The system is then said to be non-flow.

from the SFEE

$$\cancel{gz_1} + u_1 + \cancel{p_1 v_1} + \cancel{\tfrac{1}{2}c_1^2} + q = \cancel{gz_2} + u_2 + \cancel{p_1 v_2} + \cancel{\tfrac{1}{2}c_2^2} + w$$

$$u_1 + q = u_2 + w \Rightarrow q - w = u_2 - u_1$$

when $\Delta z \simeq 0$, $\Delta c^2 \simeq 0$

$$\therefore \boxed{q - w = u_2 - u_1} \quad NFEE$$

$$\boxed{q - w = h_2 - h_1} \quad SFEE$$

- Some Applications of the SFEE :-

1. Steam Boiler ; from SFEE ,

   in Boiler , $w = 0$, $c_1 \simeq c_2$, $\Delta z \simeq 0$

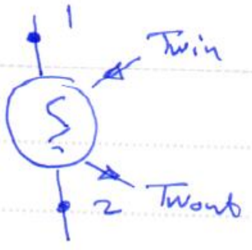
   $\therefore q = h_2 - h_1$ kJ/kg

2. Turbine ; from SFEE.

   in turbine $Q = 0$, $(c_2^2 - c_1^2/2) \simeq 0$, $\Delta z \simeq 0$

   $\therefore w = h_1 - h_2$ kJ/kg

3. Heat Exchanger: from SFEE.



in h.e

$W = 0 \quad , \Delta C \simeq 0 \quad , \Delta Z \simeq 0$

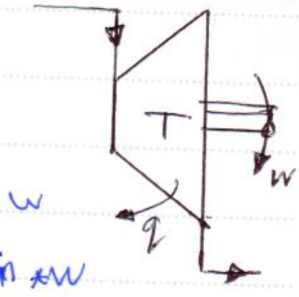
$\therefore q = h_2 - h_1$ kJ/kg heat rejected from a fluid.

$Q = \dot{m}_s (h_2 - h_1) = \dot{m}_w C_{pw} (T_{wout} - T_{win})$

"cooling water"

Ex.: In a turbine of gas turbine Unit. the gases flow through the turbine at 17 kg/s and the Power developed by the turbine is 14000 kw. the enthalPies of the gases at inlet and outlet are 1200 kJ/kg and 360 kJ/kg respectively and the velocities of gas at inlet and outlet are 60 m/s and 150 m/s respectively Find the rate at which heat is rejected from the turbine. Find also the inlet Pipe cross-sectional area when the inlet specific volume is 0.5 m³/kg.

Sol.



from Steady flow energy equation.

$gz_1 + h_1 + \frac{1}{2}C_1^2 + q = gz_2 + h_2 + \frac{1}{2}C_2^2 + w$

$z_1 \simeq z_2$, Power = 14000 kw , $P = \dot{m} * w$

$W = 14000/17 = 823.5$ kJ/kg

$\therefore q = (360 - 1200) + \frac{1}{2}(150^2 - 60^2) \times 10^{-3} + 823.5$

$= -7.05$ kJ/kg $= 7.05 \frac{kJ}{kg}$ rejected heat

$Q = \dot{m} q = 17 \times 7.05 = 119.8$ kw

$\dot{m} = \frac{CA}{v} \Rightarrow A = \frac{17 * 0.5}{60} = 0.142\ m^2 = \frac{\pi}{4} D^2 \Rightarrow D = ?$

Specific Heat :-

Is defined as the energy required to raise the temperature of a unit mass of a substance by one degree.

$$Q = m \cdot c \cdot \Delta T \quad kJ$$

c = Specific heat capacity kJ/kg.k

m = mass of substance.

Q = heat transferred to produce temperature change.

Physically the specific heat at constant Volume (C_v) can be viewed as the energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant.

The energy required to do the same as the pressure is maintained constant is the specific heat at constant pressure (C_p).

The specific heat at constant Pressure (C_p) is always greater than (C_v) because at constant pressure the system is allowed to expand and the energy for thy expansion work must also be supplied to the system

$Q = m c \Delta T$

for unit mass $q = c \cdot \Delta T \Rightarrow dq = c\,dT$

$$\therefore \boxed{c = \frac{dq}{dT}}$$

1. at constant Volume :-

from NFEE

$$q - w = \Delta U \quad \text{at } v=c \Rightarrow w=0$$

$$q = \Delta U \Rightarrow dq = du$$

$$\therefore C_v = \frac{dq}{dT} = \frac{du}{dT} \Rightarrow du = C_v \, dT$$

$$\therefore \Delta U = C_v \, \Delta T$$

at Constant Volume $\boxed{Q = \Delta U = m \, C_v \, \Delta T}$

2. at constant Pressure :-

$$W = P_2V_2 - P_1V_1$$

$$q = w + \Delta U = (P_2V_2 - P_1V_1) + (U_2 - U_1)$$

$$q = (P_2V_2 + U_2) - (P_1V_1 + U_1) = h_2 - h_1 = \Delta h$$

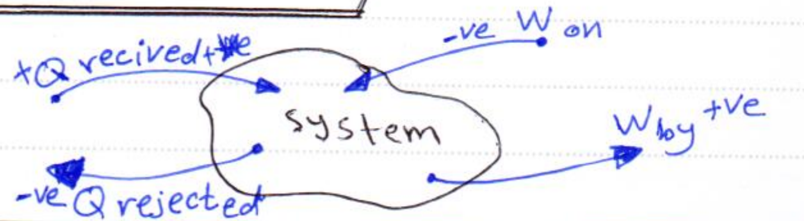
$$dq = dh$$

$$C_p = \frac{dq}{dT} = \frac{dh}{dT} \Rightarrow dh = C_p \cdot dT$$

$$\Delta h = C_p \cdot \Delta T$$

$$\boxed{Q = \Delta H = m \cdot C_p \cdot \Delta T}$$

Note :-



Sheet No.1

Q1. In an air compressor the compression take place at constant internal energy and 50 kJ of heat are rejected to the cooling water for every kg of air. Find the work required for the compression stroke per kg of air.

Q.2 1 kg of fluid is compressed reversibly according a $PV = 0.25$, final volume is one-fourth the initial volume calculate the work done on the fluid and sketch the process on P-V diagram.

Q.3. 0.05 m^3 of gas at 6.9 bar expands reversibly in a cylinder behind a piston according to law $PV^{1.2} = C$ until the volume is 0.08 m^3. Calculate the work done by the gas and sketch the process on P-V dig.

Q4. One kg of fluid expands reversibly according to a linear law from 4.2 bar to 1.4 bar. initial and volume are 0.004 m^3 and 0.02 m^3. The fluid is then cooled reversibly constant pressure and finally compressed reversibly according to law $PV = C$ back to initial condition of 4.2 bars and 0.04 m^3. Calculate the work done for each process, the net work done and sketch the cycle on P-V dia

Q.5. In the compression stroke of an internal combustion engine the heat rejected to the cooling water is 45 KJ/kg and the work input is 90 KJ/kg. Calculate the change in internal energy of the working fluid, stating whether it is a gain or a loss.

Q.6. The gases in the cylinder of an internal-combustion engine have an internal energy of 800 KJ/kg and a specific volume of 0.06 m^3/kg at the begining of expansion. The expansion of the gases may be assumed to take place according to a reversible law $PV^{1.5} = c$ from 55 bar to 1.4 bar. The internal energy after expansion is 230 KJ/kg. Calculate the heat ~~rg~~ rejected to the cylinder cooling water per kg of gases during the expansion stroke.

Q.7. A steady flow of steam enters a condenser with enthalpy of 2300 KJ/kg and a velocity of 350 m/s. The condensat leaves the condenser with an enthalpy of 160 KJ/kg and velocity of 70 m/s. Find the heat transfer to the cooling fluid per kg.

Q.8. A turbine operating under steady flow conditions receives steam at the following state: $P = 13.8$ bars, $v = 0.143\ m^3/kg$, $U = 2590\ \frac{kJ}{kg}$, $V = 30$ m/s. The state of the steam leaving the turbine is $P = 0.35$ bar, $v = 4.37\ m^3/kg$, $U = 2360$ KJ/kg, $V = 90$ m/s. Heat is lost to the surroundings at the rate of 0.25 KJ/s. If the rate of steam flow is 0.38 kg/s. What is the power developed by the turbine.

Q.9. In a Compression Stroke of gas engine the work done on the gas by the Piston is 70 kJ/kg and heat rejected to the cooling water is 42 kJ/kg. find the change of internal energy. stating whether it is gain or lost.

Q.10. A nozzle is a device for increasing the velocity of fluid. At inlet to the nozzle the enthalpy is 3026 kJ/kg and the velocity is 60 m/s. At exit from the nozzle the enthalpy is 2790 kJ/kg. The nozzle is horizontal and there is negligible heat loss from the turbine.

a- find the velocity at the nozzle exit.

b- If the inlet area is 0.1 m^2 and the specific volume at the inlet is 0.19 m^3/kg. find the mass flow rate.

c- If $v = 0.5$ m^3/kg find the exit area of the nozzle.

CHAPTER: TWO

IDEAL GAS

* * *

- Ideal gas :- Boyle's Law , Charle s's Law

- The characteristic equation of a perfect gas.
- Relation Between Specific Heat C_p , C_v
- Reversible and Irreversible Processes for the ideal gas.

1. Reversible non-flow Processes

a - Constant volume process (Isometric)

b - " Pressure " (Isobaric)

c - " temperature " (Isothermal)

d - Adiabatic process, the Relation between P & V and T

e - Polytropic "

2. Irreversible Process (closed System)

a - Paddle work ($P=c$) . b - Paddle work ($V=c$) .

3. Reversible Process (open System)

a - Constant pressure process.

b - Constant temperature . c - Polytropic .

4. Irreversible process (open system)

a - Unresisted or free expansion.

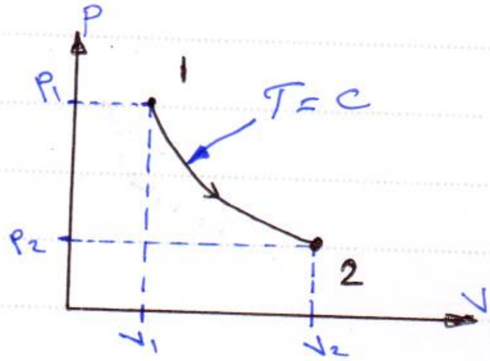
b - Throttling Process.

c - Adiabatic mixing .

IDEAL GAS :- (Perfect gas)

1. Boyle's Law :-

It is defined as: when a change of state of any gas in which the mass and the temperature remains Constant, the volume Varies inversely as the Pressure.



$$P \propto \frac{1}{V} \Rightarrow P = C * \frac{1}{V}$$

$\therefore PV = \text{Constant}$, $T = \text{Const.}$

$$\boxed{PV = C}$$ ---- Boyle's Law.

Ex. :-

A gas whose original Pressure and Volume were 300 kPa and 0.14 m³ is expanded until it's new Pressure is 60 kPa. While its temperature remains constant. What is its new volume.

Sol. : $P_1V_1 = P_2V_2 \Rightarrow V_2 = \frac{P_1}{P_2} * V_1$

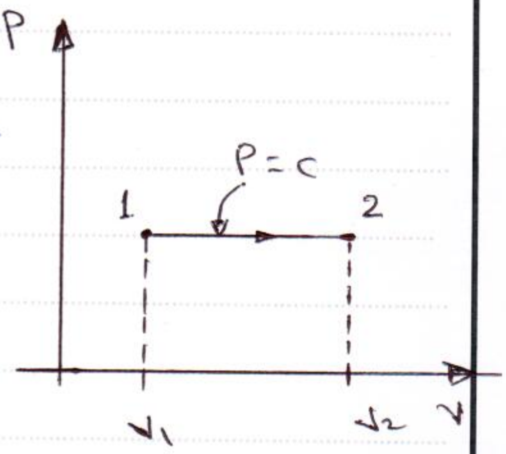
$$V_2 = 0.14 * \frac{300}{60} = 0.7 m^3$$

2. Charles's Law :-

It is defined as: when the change of state of any gas in which the mass and pressure remain constant, the volume varies in proportion with the absolute temperature.

$$V \propto T \Rightarrow V = C * T$$

$$\therefore \boxed{\frac{V}{T} = C}$$



$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad , \; P = \text{Constant}.$$

Ex.: A quantity of gas whose original volume and temp. are 0.2 m³ and 303 °C respectively, is cooled at constant pressure until it's volume becomes 0.1 m³. what will be the final temperature of the gas.

Sol. :-

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

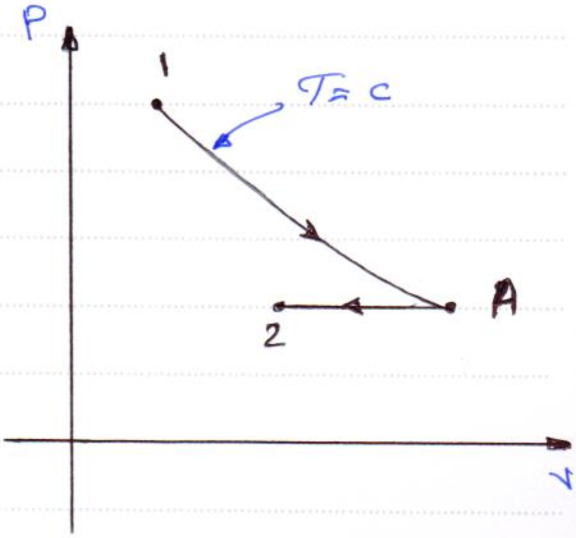
$$\Rightarrow T_2 = T_1 * \frac{V_2}{V_1}$$

$$T_1 = 303 + 273 = 576 \, k$$

$$\therefore T_2 = 576 * \frac{0.1}{0.2} = 288 \, k$$

$$t_2 = 288 - 273 = 15 \, ^\circ c$$

The characteristic equation of a perfect gas :-



the Process $1 \rightarrow A$

$PV = C$ Boyles , $T = \text{Const.}$

$\therefore P_1V_1 = P_AV_A$, $T = C \Rightarrow T_1 = T_A$

$V_A = \frac{P_1}{P_A} * V_1$ ---- (1)

the Process $A \rightarrow 2$

$V = C * T$, Charles , $P = \text{Const.}$

$\frac{V_A}{T_A} = \frac{V_2}{T_2} = \text{Const.}$, $P_A = P_2$

$V_A = \frac{T_A}{T_2} * V_2$ ---- (2)

from Boyle's Law $T_A = T_1$ Sub. in eq. (2)

$V_A = \frac{T_1}{T_2} * V_2$ ------ (3)

from eq. (1) & (3) $\Rightarrow \frac{T_1}{T_2} V_2 = \frac{P_1}{P_A} * V_1$; $P_A = P_2$

$\therefore \frac{P_1}{P_2} V_1 = \frac{T_1}{T_2} V_2 \Rightarrow \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \text{Constant}$

$$\boxed{\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = R}$$ R = gas Constant

$P_1 V_1 = R T_1$ for 1 kg

$P_1 V_1 = m R T_1$ for m kg

$m = n \cdot M$

where: m = mass kg

n = number of moles mol

M = molecular weight

$PV = mRT$ In general.

$PV = n \cdot MRT \Rightarrow MR = \frac{PV}{n \cdot T}$ (P & T are Const.)

$MR = c * \frac{V}{n}$; $\frac{V}{n} = c$ (Avagador's theorm)

$\therefore MR = R_o$; R_o: Universal gas Constant.

Avogadro's theorm: Volume of one mole of any gas is same for all gases at any temperature and Pressure.

$$\therefore R_o = \frac{PV}{nT}$$

$\because$ Volume of 1 mole at 0°C and $P = P_{atm.} = 1.01325$ bars equal to $22.7\ m^3$

$$\therefore R_o = \frac{1.01325*10^5 * 22.7}{1*(0+273)} = 8.314 \text{ kJ/kg.K}$$

$$\text{for } O_2: \; M = 32 \Rightarrow R = \frac{R_o}{M} = \frac{8314}{32} = 259 \frac{\cancel{k}J}{kgK}$$

Ex.:- A Volume of $3.6 m^3$ of O_2 initially at 220°c and Pressure 400 kPa, is Compressed reversibly at Constant temperature to final Volume of $0.06 m^3$. Calculate the mass, the final Pressure, the increase in internal energy, and the work done.

Sol.:-

$$\text{for } O_2, \; M=32 \Rightarrow R = \frac{8.314}{32} = 0.259 \text{ kJ/kgK}$$

$$PV = mRT \Rightarrow m = \frac{400*10^3*3.6}{259*(220+273)} = 11.23 \text{ kg}$$

$$P_1V_1 = P_2V_2, \; T=c \Rightarrow P_2 = \left(\frac{3.6}{0.06}\right)*400 = 24 \text{ MPa}$$

$$\text{from NFEE } Q = W + \Delta U, \; \Delta U = 0 \Rightarrow T = c$$

$$W = \int_1^2 P dv \; ; \; PV = c \Rightarrow P = \frac{c}{V}$$

$$\therefore W = \int_{v_1}^{v_2} \frac{c}{v} dv = c\int_{v_1}^{v_2} \frac{dv}{v} = c*(\ln V_2 - \ln V_1)$$

$$W = P_1V_1 * \ln \frac{V_2}{V_1} = 400*3.6*10^3 * \ln \frac{0.06}{3.6} = -5.896 \text{ MJ}$$

$$Q = W = -5.896 \text{ MJ}$$

Joule's Law :-

It is defined as :-

The internal energy of a gas is a function of temperature only and is independent of changes in pressure and Volume.

$\therefore$ If $T = C \Rightarrow \Delta U = 0$

- The Specific heat Capacities of a gas :-

a- the Constant Volume heating of a gas ;

Let a mass of a gas be heated at Constant Volume such that its temperature rises from T_1 to T_2 and its pressure rises from P_1 to P_2 . Then

Heat received by the gas $= m\, C_v\, (T_2 - T_1)$

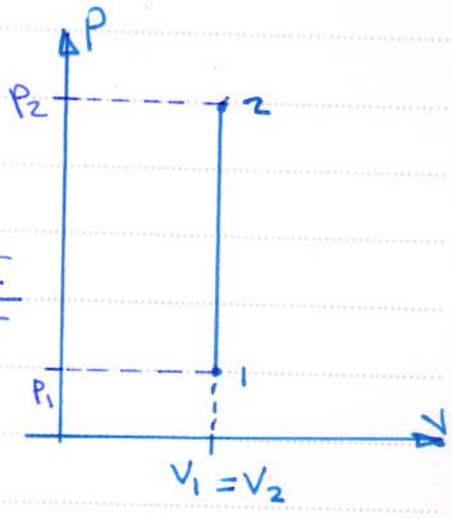
from NFEE , $Q = \Delta U + W$

$\therefore V = C \Longrightarrow W = 0 \Rightarrow Q = \Delta U$

or $m C_v (T_2 - T_1) = U_2 - U_1$

from the Perfect gas eq.

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



Ex.:- 2 kg of a gas occupying 0.7 m^3, had an original temperature of 15 °C. It was then heated at constant volume until its temperature became 135 °C. How much heat was transferred to the gas and what was its final pressure? Take, $c_v = 0.72$ kJ/kgK and $R = 0.29$ kJ/kgK.

Sol.:- $V =$ Constant

$$Q = W + \Delta U \,,\quad W = 0 \quad V = c$$

$$Q = \Delta U = m\,c_v\,(T_2 - T_1)$$

$$Q = 2 * 0.72 * (135 - 15) = 172.8 \text{ kJ}$$

$$P_1 V_1 = m R T_1$$

$$P_1 = \frac{2 * 0.29 * 288}{0.7} = 238.6 \text{ kPa}$$

Since the volume remains constant, then

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow P_2 = P_1 * (T_2 / T_1) = 238.6 * \frac{408}{288}$$

$$\therefore P_2 = 338.1 \text{ kPa.}$$

$$\text{or} \quad P_2 V_2 = m R T_2 \Rightarrow P_2 = \frac{m R T_2}{V_2}$$

$$V_1 = V_2$$

$$P_2 = \frac{2 * 0.29 * (135 + 273)}{0.7} = 338.1 \text{ kPa}$$

b. the constant pressure heating of a gas :-

Let a mass of gas be heated at constant pressure such that its temperature rises from T_1 to T_2 and its volume increases from V_1 to V_2 Then.

Heat received by the gas $= m C_p (T_2 - T_1)$

$$Q = W + \Delta U$$

$$m C_p (T_2 - T_1) = P(V_2 - V_1) + U_2 - U_1$$

$$= (PV_2 + U_2) - (PV_1 + U_1) = H_2 - H_1$$

from the characteristic eq. of perfect gas:

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

Note : $H = m C_p T$, $h = C_p T$, $\Delta h = C_p \Delta T$

$U = m C_v T$, $u = C_v T$, $\Delta u = C_v \Delta T$

Ex.: A gas whose pressure, volume and temp. are 275 kPa, 0.09 m^3 and 185 °C, respectively, has its state changed at constant pressure until its temp. becomes 15 °C. How much heat is transferred from the gas and how much work is done on the gas during the process? $R = 0.29$ kJ/kgK , $C_p = 1.005$ kJ/kgK

<u>Sol.</u> $P_1 V_1 = m R T_1 \Rightarrow m = 275 * 10^3 * 0.09 / (0.29 * 10^3 * 458)$

$m = 0.186$ kg.

$Q = m C_p (T_2 - T_1) = 0.186 * 1.005 (288 - 458) = -31.78$ kJ

(the heat has been extracted from the gas)

$P = c \Rightarrow V_2 = V_1 * \frac{T_2}{T_1} = 0.09 * \frac{288}{458} = 0.0566\ m^3$

$\therefore W = P(V_2 - V_1) = 275 * (0.0566 - 0.09) = -9.19$ kJ

- Relation Between Specific Heat "C_p, C_v" :-

from the non-flow energy eq. NFEE

$$Q = W + \Delta U$$

$$W = \int_1^2 P \cdot dV = P_2V_2 - P_1V_1$$

Ideal gas Law $PV = mRT$

$$\therefore W = mR(T_2 - T_1)$$

$$\therefore Q = mR(T_2 - T_1) + mC_v(T_2 - T_1)$$

$$= m(R + C_v)(T_2 - T_1)$$

$$\therefore Q = \Delta H = mC_p(T_2 - T_1)$$

$$\therefore mC_p(T_2 - T_1) = m(R + C_v)(T_2 - T_1)$$

$$\therefore C_p = R + C_v$$

$$\Rightarrow \boxed{(C_p - C_v) = R}$$

$\gamma = \frac{C_p}{C_v}$, γ = the ratio of the specific heat.

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

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

$$C_p = \gamma * C_v \Rightarrow \boxed{C_p = \frac{\gamma R}{\gamma - 1}}$$

Ex.: A Perfect gas have specific heat as $C_p = 0.846 \frac{kJ}{kgK}$ $C_v = 0.657$ kJ/kgK. find the gas Constant and molecular weight of gas.

Sol.: $R = C_p - C_v = 0.846 - 0.657 = 0.189$ kJ/kgK

$M = R_o/R = (8.314/0.189) = 44$

Ex.: A Perfect gas has molecular weight of 26 and a value of $\gamma = 1.26$, Calculate the heat rejected per 1 kg When a- the gas is Contained in a rigid Vessel at 3 bars and 315 °C and cooled Until the Pressure fails to 1.5 bars. b- the gas enters pipe at 280 °C and flow steady in the end of the pipe where T= 250 °C. Neglect any chang in Velocity of the gas.

Sol.: a) $Q = W + \Delta U$, rigid Vessel $\Rightarrow V = c \Rightarrow dv = 0$

$\therefore W = \int p\,dv \Rightarrow W = 0$

$\therefore Q = \Delta U = m C_v (T_2 - T_1)$

$M = 26, \gamma = 1.26, R = R_o/M = (8.314/26) = 0.3198 \frac{kJ}{kgK}$

$C_v = \frac{R}{\gamma - 1} = \frac{0.3198}{1.26 - 1} = 1.229$ kJ/kgK

$\therefore Q = 1 \times 1.226 \times (T_2 - T_1)$.

Since $v = c$ $\Rightarrow$ from the characteristic eq.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow T_2 = \frac{P_2}{P_1} * T_1 = \frac{1.5}{3}(315 + 273)$$

$\therefore T_2 = 294\,K \Rightarrow Q = 1 \times 1.266(294 - 588) = -361$ kJ
$= 361$ kJ rejected

b) Steady flow Energy Equation.

$P_1V_1 + U_1 + \frac{1}{2}C_1^2 + gZ_1 + Q = P_2V_2 + U_2 + \frac{1}{2}C_2^2 + gZ_2 + W$

$\Delta Z \simeq 0$, $\Delta C \simeq 0$, $W \simeq 0$

$\therefore q = h_2 - h_1$

$Q = m(h_2 - h_1) = mC_p(T_2 - T_1)$; $C_p = \gamma \times C_v$

$C_p = 1.26 * 1.229 = 1.548$ kJ/kg K.

$Q = 1 * 1.548 * (250 - 280) = -46.44$ kJ

$= 46.44$ kJ rejected.

Ex. :- Five kilogram of oxygen are heated from 250k to 400k at constant pressure. Calculate the change of enthalpy, change in internal energy. heat transferred and work done. $\gamma = 1.4$

Sol. :- a non-flow energy eq.

$Q = W + \Delta U$; $W = \int P dV = P(V_2 - V_1)$, $P = C$ given.

$Q = (P_2V_2 - P_1V_1) + (U_2 - U_1) = (P_2V_2 + U_2) - (P_1V_1 + U_1)$

$Q = H_2 - H_1 = mC_p(T_2 - T_1)$ for $P = c$ only.

for O_2 $M = 32$, $\gamma = 1.4$, $R = R_o/M = (8.314/32) = 0.2598 \frac{kJ}{kg\,k}$

$C_p = \frac{\gamma R}{\gamma - 1} = (1.4 * 0.2598/0.4) = 0.9093$ kJ/kg.k

$\Delta H = 5 * 0.9093 * (400 - 250) = 692$ kJ

$\Delta U = mC_v(T_2 - T_1)$; $C_v = \frac{R}{\gamma - 1} = (0.2598/0.4) = 0.6495 \frac{kJ}{kg\,k}$.

$\Delta U = 5 * 0.6495 * (400 - 250) = 487.125$ kJ

$Q = W + \Delta U = \Delta H$ at $P = $ Const.

$\therefore W = Q - \Delta U = 692 - 487.125 = 204.875$ kJ

Work done by the system.

Ex.: An Oxygen Cylinder has a capacity of 300 L, and Contains O_2 at 3.1 MPa and 18 °C. The Valve is open and Some gas is used. If the pressure and temp. of the Oxygen fall to 1.7 MPa and 15 °C. Find the mass of oxygen used. If after the valve is closed the oxygen remain in the cylinder is gradualy attains its initial temp. of 18 °C. Find the amount of heat transfer through the Cylinder wall, Oxygen density at 0 °C and 0.101325 MPa is 1.429 kg/m³.

Sol.:- $P_1 V_1 = m R T_1 \Rightarrow m = \frac{P_1 V_1}{R T_1}$

$$R = (8.314/32) = 0.26 \text{ kJ/kg k}$$

$\therefore$ initial mass $= (3.1 \times 10^3 \times 300 \times 10^{-3}) / (0.26 \times (18+273)) = 12.29$ kg

$\therefore m_1 = 12.29$ kg

final mass $= (1.7 \times 10^3 \times 300 \times 10^{-3}) / (0.26 \times (15+273)) = 6.8$ kg

$\therefore m_2 = 6.8$ kg

mass used $= m_1 - m_2 = 12.29 - 6.8 = 5.49$ kg

$Q = W + \Delta U$, $V = c \Rightarrow W = 0 \Rightarrow Q = \Delta U$

$\therefore Q = m C_v (T_2 - T_1)$; $C_v = (R/(\gamma-1)) = (0.26/0.4) = 0.65 \ \text{kJ/kg k}$

$\therefore Q = 6.8 \times 0.65 (18 - 15) = 13.26$ kJ

Sheet 2.

Q1.

The molecular weight of carbon dioxide (CO_2) is 44. In an experiment the value of γ was found to be 1.3. Assuming that CO_2 is a perfect gas. Calculate the gas constant R and the specific heats at constant pressure and constant volume. Ans. $[0.189, 0.63, 0.819 \frac{kJ}{kg\,K}]$

Q2. Calculat the internal energy and enthalpy of 1 kg of air occupying $0.05\ m^3$ at 20 bars. If the internal energy is increased by 120 kJ/kg as the air compressed to 50 bars. Calculate the new volume occupied. Ans $[250, 350 \frac{kJ}{kg\,K}, 0.0296\ m^3]$

Q3. When a certain perfect gas is heated at constant pressure from $15^\circ C$ to $95^\circ C$, the heat required 1130 kJ/kg. While when the same gas is heated at constant volume between the same temperature limits above, the required is 808 kJ/kg. Calculate C_p, C_v, γ, R and M of the gas.

Q4. In an air compressor the pressure at inlet and outlet are 1 bars & 15 bars respectively. The temperature of the air at inlet is $15^\circ C$ and the volume at beging of compression is three times that at the end of the compression. Calculate the temp. at outlet and the increase in internal energy.

Q5. The exhaust gas leaving an oil engine is passed through a heat exchanger which consist of tubes surrounding by water. The gas enters at 327 °C and leaves at 193 °C. The water enters the exchanger at 17 °C and leaves at 56 °C. If the mass flow rate of water is 2.54 kg/min. Determine the mass flow rate of gas.

$C_p = 1.04$ kJ/kgK , $C_{pw} = 4.186$ kJ/kgk

Ans. [2.98 kg/min]

Q6.

A working fluid enters a steady-flow system with velocity 30 m/s and leaves with velocity 140 m/s. The mass flow rate is 9 kg/s. The properties of the fluid are at entry, 13.8 bars, 0.122 m^3/kg, internal energy 422 kJ/kg and exit properties are 1.035 bars, 0.805 m^3/kg, internal energy 208 kJ/kg. The heat transfer from the system is 4.22 kJ/kg. Determine the work transfered in kw from the system.

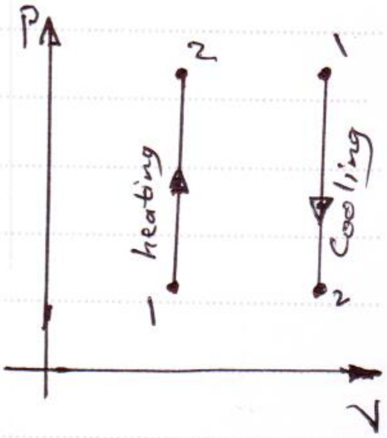
- Reversible and Irreversible Processes for The Ideal Gas.

1. Reversible non-flow Processes:

a- Constant Volume Process (Isometric).

from the non flow E.E.

$Q = W + \Delta U$



$W = \int P\,dV \quad , V = C \Rightarrow dV = 0$

$\therefore W = 0$

$\Rightarrow Q = \Delta U$

$$\boxed{Q = m C_v (T_2 - T_1)}$$

b- Constant Pressure Process (Isobaric)

from the non-flow E.E.

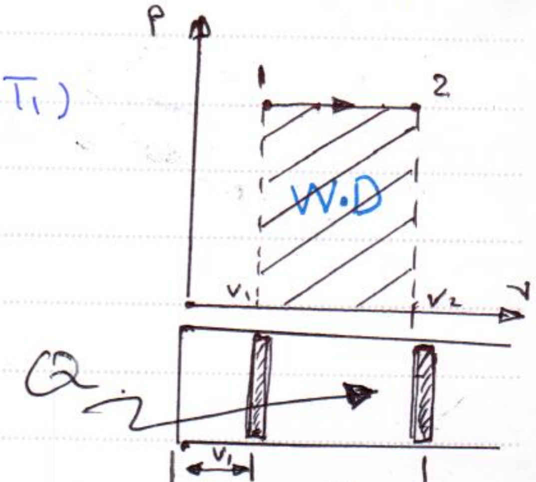
$Q = W + \Delta U \; ; \; W = P_2 V_2 - P_1 V_1 = m R (T_2 - T_1)$

$\Delta U = m C_v (T_2 - T_1)$

$\therefore Q = m R (T_2 - T_1) + m C_v (T_2 - T_1)$

$= m (R + C_v)(T_2 - T_1)$

$= m C_p (T_2 - T_1) = \Delta H$



$Q = m C_p (T_2 - T_1)$

Ex. : 0.05 kg of air is heated at constant pressure of 2 bars until the volume occupied is 0.0658 m³. Calculate the heat supplied and work done. when the initial temperature is 130 °C.

Sol. :-

the non-flow energy eq.

$Q = W + \Delta U$

$W = P(V_2 - V_1) = mR(T_2 - T_1)$

$\Delta U = m C_v (T_2 - T_1)$

$\therefore Q = m C_p (T_2 - T_1)$

$P_2 V_2 = m R T_2 \Rightarrow T_2 = (2 * 10^2 * 0.0658)/(0.05 * 0.287)$

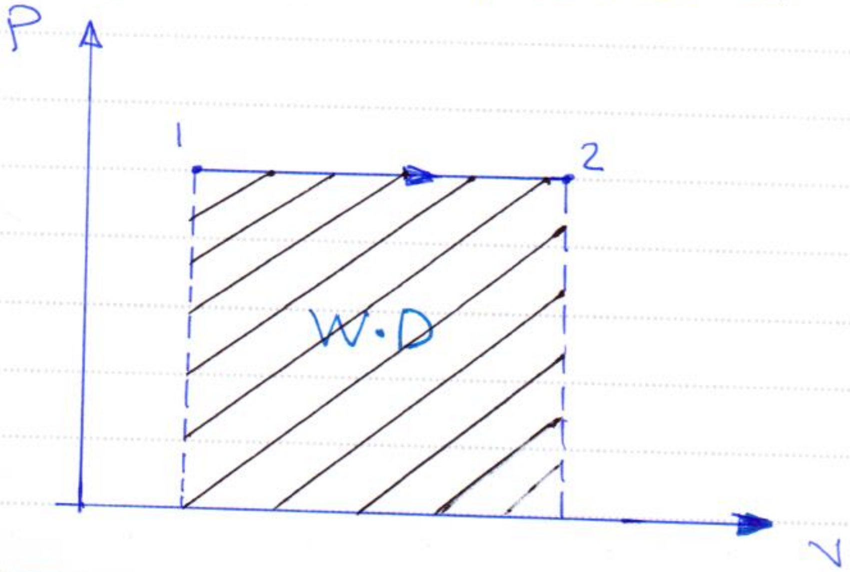
$\therefore T_2 = 912\ k$

$\therefore Q = 0.05 * 1.005 (912 - 403) = 25.6\ kJ$

$W = 0.05 * 0.287 * (912 - 403) = 7.38\ kJ$

$\Delta U = 0.05 * 0.717 * (912 - 403) = 18.27\ kJ$

$Q = W + \Delta U = 7.38 + 18.27 = 25.65\ kJ$.

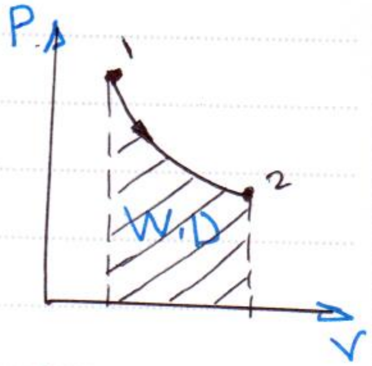


C. Constant temperature Process (Isothermal)

from non-flow E. E

$Q = W + \Delta U \quad ; \quad \Delta U = m C_v (T_2 - T_1)$

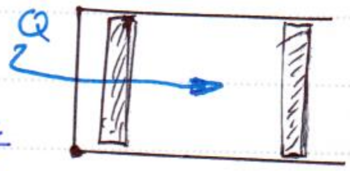
Since $T = C \Rightarrow \Delta U = 0$



$W = \int P \, dV$, we have $\frac{PV}{T} = C$

$T = \text{Const.} \Rightarrow PV = C \Rightarrow P = \frac{C}{V}$

$W = \int \frac{C}{V} dV = C * \ln \frac{V_2}{V_1}$



$\therefore W = PV \ln \frac{V_2}{V_1} = mRT_1 \ln \frac{V_2}{V_1}$

$$\therefore \boxed{Q = PV \ln \frac{V_2}{V_1} = PV \ln \frac{P_1}{P_2} = mRT \ln \frac{P_1}{P_2}}$$

Ex. A quantity of gas has initial Pressure 140 kPa and Volume 0.14 m³. It is then compressed as a pressure of 700 kPa while the temperature remains constant. Determine the final volume of the gas.

Sol. $T = C$

from Characteristics eq. $\Rightarrow \frac{P_1 V_1}{\cancel{T_1}} = \frac{P_2 V_2}{\cancel{T_2}}$

$T_1 = T_2 \Rightarrow P_1 V_1 = P_2 V_2$

$\Rightarrow V_2 = \frac{P_1}{P_2} * V_1 = \frac{140}{700} * 0.14 = 0.028 \text{ m}^3$

Ex. 1 kg of nitrogen Molecular weight 28 is Compressed reversibly and Isothermally from 1.01 bar & 20 °c to 4.2 bar Calculte the work done and the heat flow during the Process. Assuming nitrogen to be a perfect gas.

Sol.

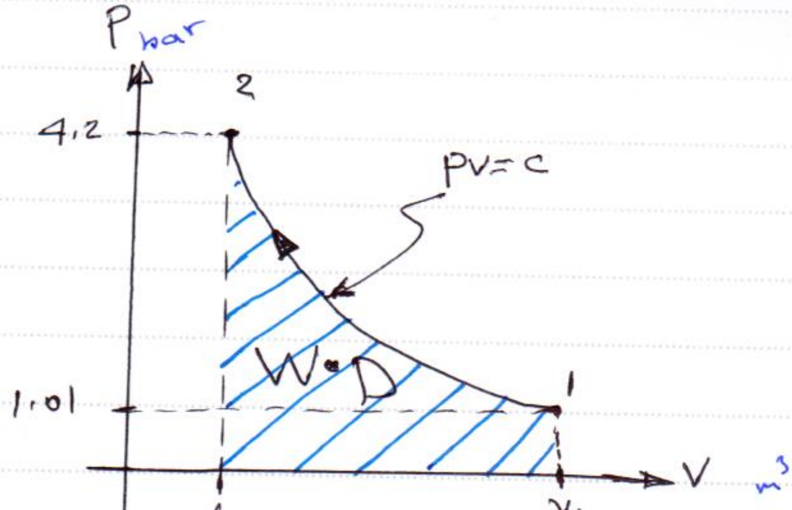
$$R = \frac{R_o}{M} = 8.314/28 = 0.297 \ kJ/kg\,K$$

$$W = mRT \ln\frac{P_1}{P_2} = 0.297 * 293 \cdot \ln\frac{1.01}{4.2} = 124 \ \frac{kJ}{kg}$$

$$\therefore Q = W \Rightarrow \therefore Q = -124 \ \frac{kJ}{kg}$$

$$W = +124 \ \frac{kJ}{kg} \ \text{(Comp.)}$$

$$Q = +124 \ kJ/kg \ \text{(heat rejected.)}$$



d. Adiabatic Process:

In this Process the System must be in thermal insulated to prevent the heat transfer between the System and surrounding.

To find the Relation between P & V from non-flow E.E.

$$Q = W + \Delta U \quad , \text{adiabatic Process} \Rightarrow Q = 0$$

$$\left.\begin{array}{ll} dQ = dW + dU & \Rightarrow dq = dw + du \\ dU = mc_v\, dT & \Rightarrow du = c_v\, dT \\ dW = P\, dV & \Rightarrow dw = P\, dv \end{array}\right] \text{Per unit mass}$$

$$\therefore dq = c_v\, dT + P\, dv$$

$$Pv = RT \Rightarrow P = \frac{RT}{v}$$

$$\therefore \left(dq = c_v\, dT + RT\frac{dv}{v}\right) \div T$$

$$0 = c_v \frac{dT}{T} + R\frac{dv}{v} \quad \div c_v$$

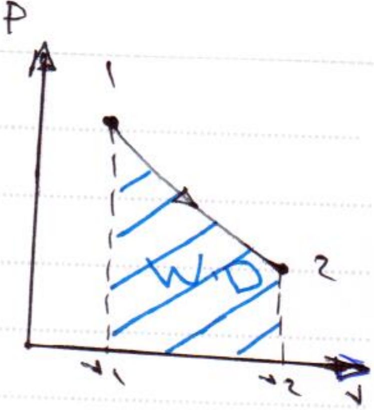
$$0 = \frac{dT}{T} + \frac{R}{c_v}\frac{dv}{v} \quad ; \quad c_v = \frac{R}{\gamma - 1}$$

$$\Rightarrow \therefore \frac{R}{c_v} = (\gamma - 1)$$

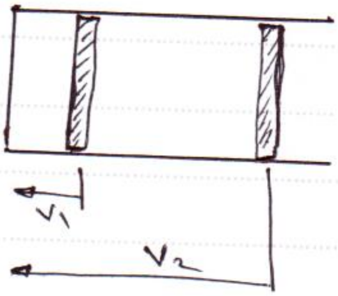
$$0 = \frac{dT}{T} + (\gamma-1)\frac{dv}{v}$$

$$\int 0 = \int_{T_1}^{T_2}\frac{dT}{T} + (\gamma-1)\int_{v_1}^{v_2}\frac{dv}{v}$$

$$\ln T + (\gamma-1)\ln V = c$$



$$PV = RT \Rightarrow T = \frac{PV}{R}$$



$$\ln\left(\frac{PV}{R}\right) + (\gamma-1)\ln V = c$$

$$\ln\frac{PV\cdot V^{(\gamma-1)}}{R} = c$$

$$\frac{PV^{\gamma}}{R} = e^{c} \Rightarrow PV^{\gamma} = R*e^{c} = c$$

$\therefore PV^{\gamma} = c$ adiabatic Process

The non-flow E. E.

$Q = W + \Delta U$; $Q = 0 \Rightarrow W = -\Delta U$

$W = mc_v(T_1 - T_2) = m\frac{R}{\gamma-1}(T_1 - T_2)$

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

Adiabatic work

– The Relation between P & V and T in Adiabatic Process :-

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow \frac{P_1}{P_2} = \frac{V_2}{V_1} * \frac{T_1}{T_2} \text{ ----- (1)}$$

adiabatic Process $\Rightarrow P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$

$$\therefore \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} \text{ ----- (2)}$$

Sub. eq. (1) in eq. (2)

$$\left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{V_2}{V_1}\right) * \left(\frac{T_1}{T_2}\right)$$

$$\Rightarrow \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \text{ ----- (3)}$$

Sub. eq. (2) in eq. (3)

where $\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/\gamma}$

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

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

Ex. Air at 1.02 bar, 22°C initially occupying a cylinder Volume of 0.015 m³, is compressed reversibly and adiabatically by a Piston to a pressure of 6.8 bars. Calculate the final temperature, the final Volume, and the work done on the mass of air in the Cylinder.

Sol.

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

$$T_2 = (22+273) * \left(\frac{6.8}{1.02}\right)^{\frac{1.4-1}{1.4}} = 507.5 \ K$$

$$T_2 = \text{final temp.} = 507.5 \ K$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma} \Rightarrow V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} * V_1$$

$$\therefore V_2 = 0.015 * \left(\frac{1.02}{6.8}\right)^{\frac{1}{1.4}} = 0.00388 \ m^3$$

$Q = W + \Delta U$, $Q = 0$ adiabatic pro.

$$\therefore W = U_1 - U_2 = m \, c_v (T_1 - T_2)$$

$$P_1 V_1 = m R T_1 \Rightarrow m = P_1 V_1 / R T_1$$

$$m = (1.02 * 10^5 * 0.015) / (0.287 * 10^3 * 295)$$

$$m = 0.0181 \ kg$$

$$\therefore W = 0.0181 * 0.717 * (295 - 507.5) = -2.76 \ kJ$$

total work input = 2.76 kJ

e- Polytropic Process :-

This general case of expansion or compression of a substance according to the law $PV^n = C$, It is called a Polytropic expansion or compression or a Polytrope.

It is should be noted that the value of the constant "C" will change with each change of condition, So also will the value of 'n" which is called the "index" of the expansion or compression or the Polytropic exponent.

$$PV^n = C$$

The non-flow energy equation

$$Q = W + \Delta U$$

$$W = \int P\,dV = C\int \frac{dV}{V^n} = C\int V^{-n}\,dV$$

$$W = PV^n\left[\frac{V^{-n+1}}{-n+1}\right]_1^2 = \frac{P_2V_2^{n}\cdot V_2^{-n+1} - P_1V_1^{n}\cdot V_1^{-n+1}}{-n+1}$$

$$W = \frac{P_2V_2^{*} - P_1V_1}{-n+1} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$W = \frac{mR(T_1 - T_2)}{n-1}$$

$$\Delta U = mC_v(T_2 - T_1) = -mC_v(T_1 - T_2)$$

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

$$\Delta U = \frac{-mR(T_1 - T_2)}{\gamma - 1}$$

$$\therefore Q = \frac{mR(T_1 - T_2)}{n-1} - \frac{mR(T_1 - T_2)}{\gamma - 1}$$

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

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

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

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

$$\boxed{\therefore Q = \left(\frac{\gamma - n}{\gamma - 1}\right) * W}$$

In a polytropic Process the value of n depends on the a amount of heat added or rejected and on the work done during the Process $PV^n = C$

when :

1. $n = 0 \longrightarrow PV^0 = C \longrightarrow P = C$ (Isobaric)
2. $n = 1 \longrightarrow PV^1 = C \longrightarrow PV = C$ (Isothermal)
3. $n = \gamma \longrightarrow PV^\gamma = C \longrightarrow Q = 0$ (adiabatic)
4. $n = \infty \longrightarrow PV^\infty = C \rightarrow P^{1/\infty} V = C \longrightarrow V = C$ (Isometric) or (Isochoric)

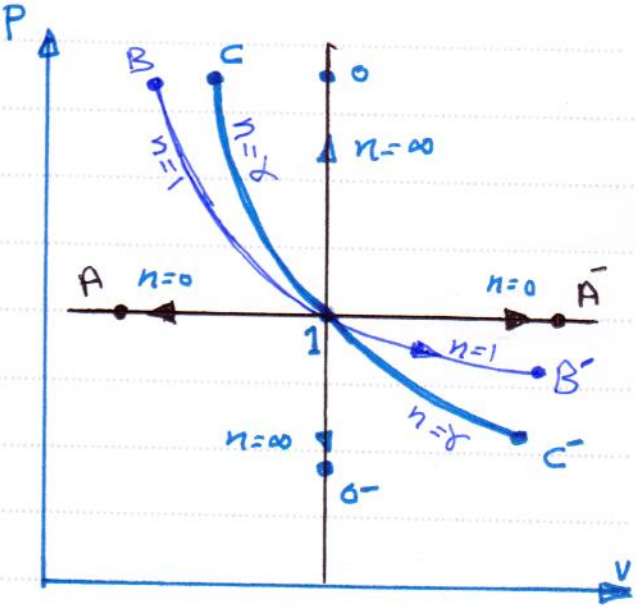
Processes :-

$1 \longrightarrow A$ Cooling at $P=C$
$1 \longrightarrow A'$ Heating at $P=C$

$1 \longrightarrow B'$ Expansion at $T=C$
$1 \longrightarrow B$ Compression at $T=C$

$1 \longrightarrow C$ Adiabatic Comp. $PV^\gamma = C$
$1 \longrightarrow C'$ ″ Expansion

$1 \longrightarrow D$ Heating at $V=C$
$1 \longrightarrow D'$ Cooling ″ ″



– Work and the hyperbolic Process :-

The hyperbolic Process is a Particular case of the Polytropic Process, $PV^n = C$, being the case when $n = 1$. Thus, the law for the hyperbolic Process is $PV = C$

For a hyperbolic change from State 1 to State 2.

$$P_1V_1 = P_2V_2$$

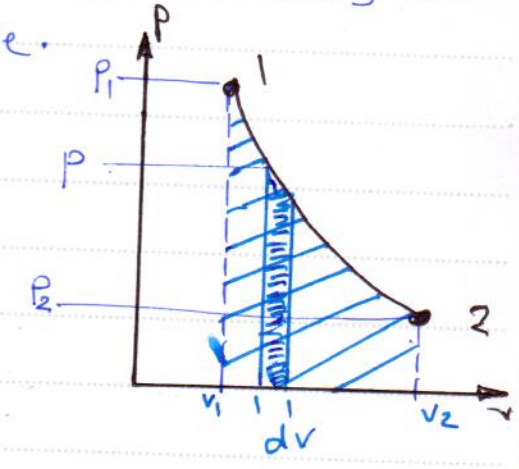
An expression for the work done during a Polytropic Process has already been determined.

$$\text{Work done} = \frac{P_1V_1 - P_2V_2}{n-1}$$

for hyperbolic Process, $P_1V_1 = P_2V_2$ & $n = 1$

$$\therefore \text{Work done} = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{0}{0}$$

to compute the work done. It is necessary to determine the area under the curve.



$$\text{Work done} = \int_{v_1}^{v_2} P\,dv \quad , P = \frac{c}{v}$$

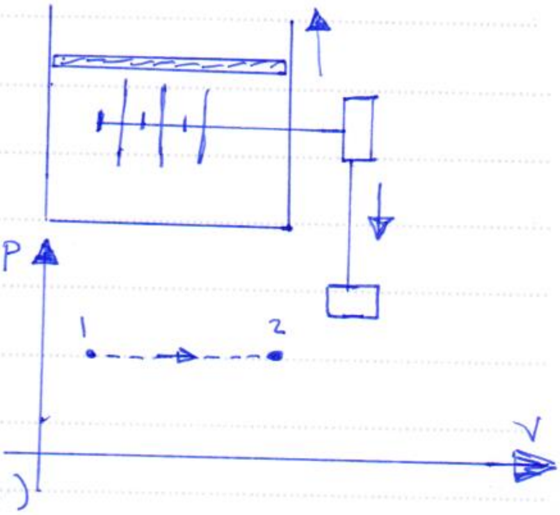
$$W = c\int_{v_1}^{v_2} \frac{dv}{v} = c\left[\ln v\right]_{v_1}^{v_2}$$

$$= c\left[\ln v_2 - \ln v_1\right] = c\ln\frac{v_2}{v_1}$$

$$\boxed{W = PV\ln\frac{V_2}{V_1}}$$

2. Irreversible Processes (close system)

a. Paddle Work ($P = C$)



W_p = Paddle Work

from non-flow E.E

$Q = \Delta U + W + W_p$

$\Delta U = m C_v (T_2 - T_1)$

$W = P(V_2 - V_1) = m R (T_2 - T_1)$

$W_p = -ve$ Since it is done on the system

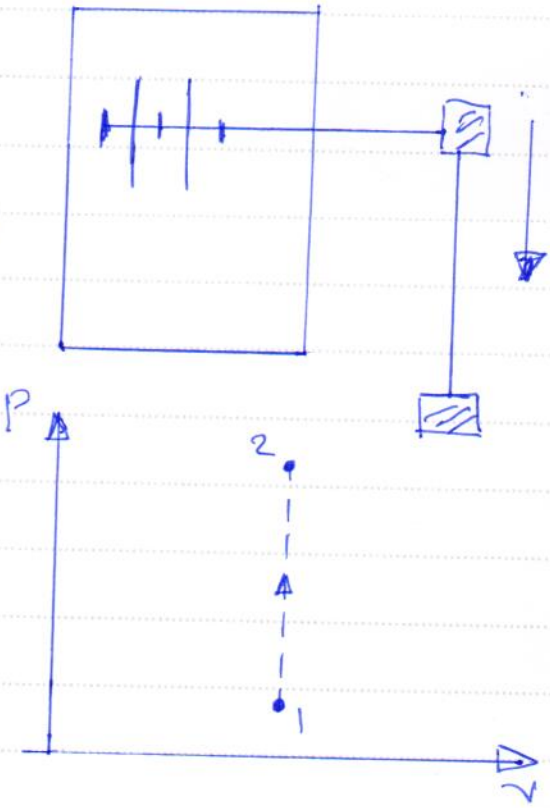
b. Paddle work $V = c$

$Q = W + \Delta U + W_p$

$W = 0 \quad V = c \,, \; Q = 0$

$\Delta U = m C_v (T_2 - T_1)$

$W_p = -ve$ done on the System.



Ex.:- A constant pressure adiabatic system contain 0.13 kg of air at 1.3 bar. The system recives paddle work. The temperature of air rises from 29 to 185 °c. Find the total work. mechanical work, change in internal energy and enthalpy. Take $R = 0.287\ kJ/kg.k$, $\gamma = 1.4$

Sol.:- $Q = W + \Delta U + W_P$, $Q = 0$ adiabatic

$W = mR(T_2 - T_1) = 0.13 * 0.287 (185 - 29) = 5.82\ kJ$

$\Delta U = m C_v (T_2 - T_1)$

$\Delta U = 0.13 * 0.717 (185 - 29) = 14.5\ kJ$

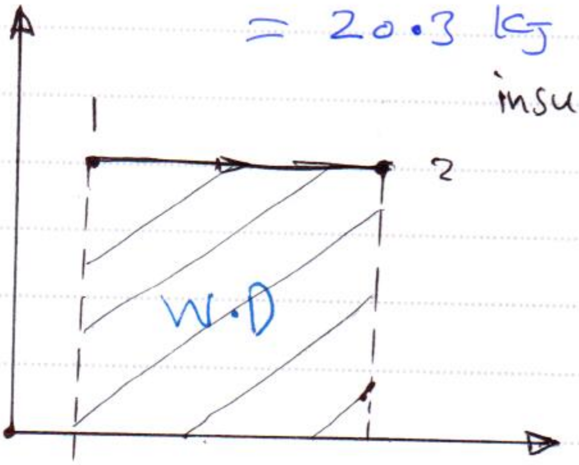
$Q = W + \Delta U + W_P$

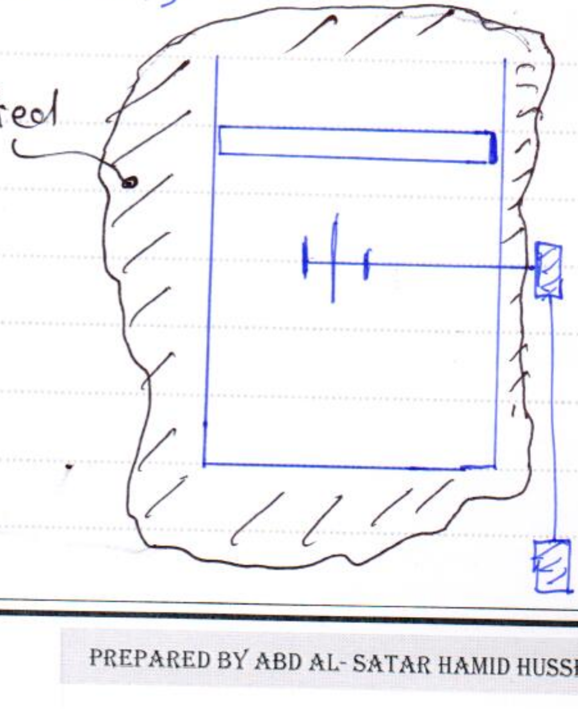
$0 = 5.82 + 14.5 + W_P \Rightarrow W_P = -20.32\ kJ$

$\Delta H = m C_p (T_2 - T_1)$

$= 0.13 * 1.005 (185 - 29)$

$= 20.3\ kJ$





Sheet No. 3

Q.1

Oxygen (M = 32) expands reversibly in a cylinder behind a piston at constant pressure of 3 bars. the initial volume is 0.01 m^3 and finally is 0.03 m^3. the initial temperature is 17 °C. Calculate the work done by the Oxygen and the heat flow to or from the cylinder walls during the expansion. Take $C_p = 0.917$ kJ/kg K. Ans: [6 kJ, 21.25 kJ]

Q2

0.05 m^3 of a perfect gas at 6.3 bars undergoes a reversible isothermal process to a pressure of 1.05 bars. Calculate the heat flow to or from the gas. Ans: [56.4 kJ]

Q3

1 kg of air at 1 bar, 15 °C is compressed reversibly adiabatically to a pressure of 4 bars, calculate the final temperature and the work done on the air. Ans [155, 100.5 $\frac{kJ}{kg}$]

Q4

1 kg of air at 1.02 bar & 20 °C is compressed reversibly according to a Law $PV^{1.3} = C$, to a pressure of 5.5 bar. Calculate the work don on the air and the heat flow during the compression.

Ans [133.5 kJ, -33.38 kJ]

Q5

Nitrogen M = 28 expands reversible in a perfectly thermally insulated cylinder from 3.5 bars. 200 °C to a volume of 0.09 m³. If the initial volume occupied was 0.03 m³, Calculate the work done during the expansion. Assuming nitrogen to be Perfect gas and take $C_v = 0.714$ KJ/KgK Ans [9.31 KJ]

Q6

0.05 kg of Carbon dioxide M = 44, occupying a volume of 0.03 m³ at 1.025 bar. is Compressed reversibly until the Pressure is 6.15 bars. calculate the final temperature, the work done on the CO_2, and the heat flow to or from the cylinder walls.

a. When the process is according to a Law $PV^{1.4} = C$

b. " " " " " isothermal.

c. " " " " " take place in a perfectly thermally insulated Cylinder, $\gamma = 1.3$.

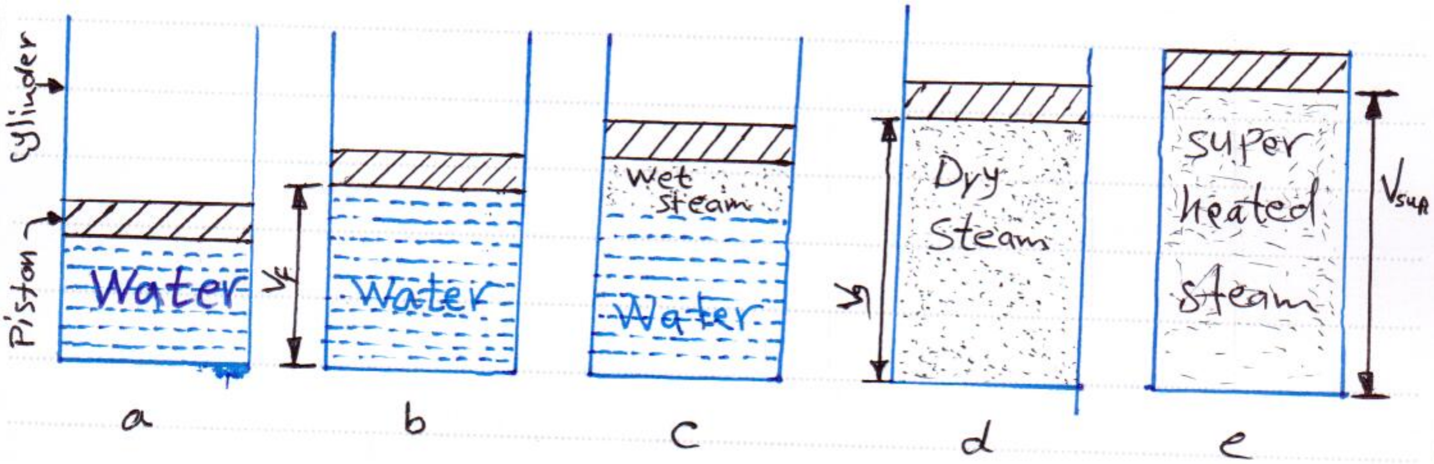
Ans [270 °C, 5.133 kJ, 1.713 kJ, 52.6 °C, 5.5 kJ, −5.5 kJ, 219 °C, 5.25 kJ, 0 kJ].

" Steam and two-Phase System "

= Steam :-

Is a vapour of water, and is invisible when pure and dry. It is used as the working substance in the operation of steam engines and steam turbines. Steam does not obey laws of perfect gases, until it is perfectly dry.

= Formation of Steam at Constant Pressure for water :-



Consider 1 kg of water at 0 °C contained in the Piston-cylinder arrangement as shown in the fig.(a).

The Piston maintain a constant Pressure in the cylinder If we heated the water contained in the cylinder, it will be converted into steam as below :-

1. The volume of water will increase slightly with the increase in temperature as shown in fig (b). It will cause the piston to move slightly upwards and hence work is obtained. This increase in volume of water is generally neglected for all types of calculations.

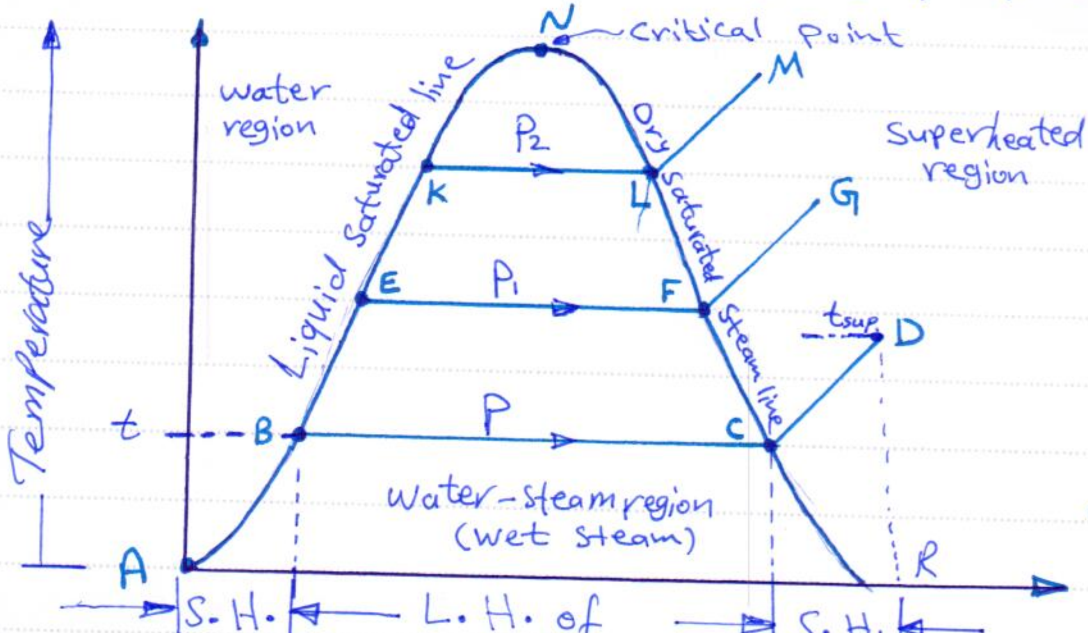
2. On further heating temperature reaches boiling point. The boiling point of water at normal atmospheric pressure of 1.01325 bar is 100 °c, but it increases with the increase in pressure. when the boiling point is reached, the temperature remains constant and the water evaporates, thus pushing the piston up against the constant pressure. Consequently the specific volume of steam increase as shown in fig. (c). At this stage the steam will have some particles of water in suspension and is termed as « wet steam ». This process will continue till the whole water is converted into wet steam.

3. On further heating, the particles in suspension will be converted into steam. The entire steam in such a state is termed as « dry steam » or « saturated steam » as shown in fig. (d). Practically the dry steam behaves like a perfect gas.

4. On further heating, the temperature of the steam starting rising. The steam in such a state is termed as superheated steam as shown in fig. (e).

Temperature vs. Total Heat Graph during Steam formation :-

The process of steam formation may be represented on a graph, whose abscissa represents the total heat and the vertical cordinate represents the temperature. The point "A" represents the initial condition of water at 0 °C and pressure P (in bar) as shown in fig. below. Line ABCD shows the relation between temperature and heat at a specific pressure of P (in bar).



Temp. - total heat graph during steam formation.

During the formation of the superheated steam from water at freezing point, the heat is absorbed in the following three stages :-

1. The heating of water up to boiling temp or saturation temperature « t_s » is shown by « AB ». The heat absorbed by the water is AP, known as sensible heat (S.H.) or liquid heat or total heat of water.
2. The change of state from liquid to steam is shown by « BC ». The heat absorbed during this stage is « PQ » known as latent heat (L.H.) of vaporisation.
3. The superheating process is shown by « CD ». The heat absorbed during this stage is « QR » known as Heat of superheat (H.S.). line AR represents the total heat of the superheated steam.

If the pressure is increased « say P_1 bar », the boiling temp. also increase. The point « E » represents the boiling temp. or saturation temp. at pressure (P_1) and (F) is the point of dry saturated steam. Line « FG » shows the constant pressure process, in which the steam is superheated. The line passing through the points « A, B, E, K » is known as « Saturated Liquid Line » which forms boundary line between water and steam. Similarly a line passing through dry steam points « L, F, C » known as « dry Saturated Steam Line » which forms boundary line between wet and superheated steam.

It may also be noted from the fig., that when the pressure and saturation temperature increases, the latent heat of vaporisation decreases. It becomes zero at point « N » when liquid and dry steam lines ~~melt~~ meet. This point « N » is known as « Critical Point » and at this point, the liquid and vapour phases merge. The temperature corresponding to critical point « N » is known as critical ~~point~~ temperature and the pressure is known as critical pressure. For steam, the critical temp. is (374.15 °C) and critical pressure is (221.2 bars).

Important Terms for Steam:-

1. Wet Steam:-

When the steam contains moisture or particles of water in suspension, it is said to be wet steam. It means that the evaporation of water is not complete and the whole of the latent heat has not been absorbed.

2. Dry Saturated Steam:-

When the wet steam is further heated and it does not contain any suspended particles of water, it is known as dry saturated steam. The dry saturated steam has absorbed its full latent heat and behaves partically, in the same way as a perfect gas.

3. Superheated Steam :-

When the dry Steam is furtherheated at a Constant Pressure, thus raising its temperature, it is Said to be Superheated Steam. Since the Pressure is Constant, therefore the volume of Superheated Steam increases.

4. Dryness fraction or quality of wet Steam :-

It is the ratio of the mass of actual dry Steam to the mass of Same quantity of wet Steam, and generally denoted by « x » Mathematically

$$\boxed{x = \frac{m_g}{m_g + m_f} = \frac{m_g}{m}}$$

m_g = mass of actual dry Steam.
m_f = " " water in suspension.
m = " " wet steam.

5. Sensible heat of water :-

It is the amount of heat absorbed by 1 kg of water. when heated at a Constant Pressure, from the freezing Point « 0 °C » to the temperature of formation of steam. The sensible heat is also known as Liquid heat.

The specific heat of water at constant Pressure is usually taken as 4.2 kJ/kg.k .

$Q_{sensible}$ = mass * specific heat * Rise in temp.

$$Q_{sen} = m C_p (T_2 - T_1) = m (h_2 - h_1)$$

$h_2 , h_1 \equiv$ Enthalpy of fluid .

6. Latent heat of vaporisation :-

It is the amount of heat absorbed to evaporate 1 kg of water, at it's boiling point or saturation temp. without change of temp. It is denoted by " h_{fg} " and its value depends upon the pressure.

The heat of vaporisation of water or latent heat of steam is 2257 kJ/kg at atmospheric pressure.

It has been experimentally found that the value of h_{fg} decreases as the pressure increases and it's zero at critical ~~p~~ressure.

If the steam is wet with a dryness fraction (x), then the heat absorbed by it during evaporation is $x h_{fg}$.

7. Enthalpy or total heat of steam:-

It is amount of heat absorbed by water from freezing point to saturation temperature plus the heat absorbed during evaporation.

∴ Enthalpy = Sensible heat + Latent heat

It is denoted by h_g and its value for dry saturated steam may be read directly from the steam table

The expression for the enthalpy of wet steam, dry steam and superheated steam are follows :-

i- Wet steam: the enthalpy of wet steam is given by

$$h = h_f + X \cdot h_{fg} \quad ; \quad h_{fg} = h_g - h_f$$

$h_f = u_f + P V_f$

ii- Dry Steam: $X = 1$

$$\therefore h = h_f + h_{fg} = h_f + (h_g - h_f) = h_g$$

iii- Superheated Steam: If further add heat to the dry steam, its temperature increases while pressure remaining constant. This increase in temp. shows the superheat stage of the steam. Thus the total heat required for the steam to be superheated.

h_{sup} = Total heat for dry steam + Heat for superheated steam.

$$h_{sup} = h_f + h_{fg} + C_p * (t_{sup.} - t_s) = h_g + C_p (t_{sup.} - t_s)$$

where:

C_p = Specific heat at constant pressure for superheated steam.

$t_{sup.}$ = Temp. of superheated steam

t_s = Saturation temp. at the given pressure.

$(t_{sup} - t_s)$ = degree of superheated

C_p for steam lies between 1.67 to 2.5 KJ/Kg.K

8. Specific Volume of steam: It is the volume occupied by the steam per unit mass at given temperature and pressure.

☞ The expression for the volumes occupied by steam are as follows:

1- Wet steam: Consider 1 kg of wet steam of dryness fraction X. Known this steam will has X kg of dry steam and (1 – X) kg of water. let V_f be the volume of 1 kg of water, then

Volume of 1 kg of wet steam $= X V_g + (1 - X) V_f$

Since V_f is very small as compared to V_g, therefore the $(1 - x) V_f$ may be neglected

$\therefore V = x * V_g$ m^3/kg

2- Dry Steam: We known at dry saturated the mass of water in suspension is zero and dryness fraction is unity.

$\therefore V = V_g$

3. Superheated steam

$$\frac{V_{sup.}}{T_{sup.}} = \frac{V_g}{T} \Rightarrow V_{sup.} = \frac{V_g * T_{sup.}}{T}$$

Ex. : Find the enthalpy, internal energy and the specific volume of saturated water at 2 bars.

Sol.

$P = 2$ bars

from steam table at 2 bars.

$h = h_f = 505$ kJ/kg ; $u = u_f = 505$ kJ/kg ; $v_f = 0.001 \frac{m^3}{kg}$

Ex. : Find the specific volume, enthalpy, entropy and internal energy of vapor at 18 bars and dryness fraction or quality is (0.9).

Sol.

$X = 0.9 \Rightarrow$ Wet steam

from steam table at 18 bars

$v_g = 0.114$ m³/kg ; $h_f = 885 \frac{kJ}{kg}$; $h_{fg} = 1912 \frac{kJ}{kg}$; $u_f = 883 \frac{kJ}{kg}$

$u_g = 2598$ kJ/kg ; $S_f = 2.398$ kJ/kg.K ; $S_{fg} = 3.981$ kJ/kg.K

$v = x\, v_g = 0.9 * 0.114 = 0.0994$ m³/kg

$h = h_f + x\, h_{fg} = 885 + 0.9 * 1912 = 2605$ kJ/kg

$u = u_f + x\, u_{fg} = 883 + 0.9 * (2598 - 883) =$

$S = S_f + x\, S_{fg} = 2.398 + 0.9 * 3.981 = 5.98$ kJ/kg.K

Ex.: Steam is initially saturated at 6 bars. Find the specific volume, internal energy, enthalpy and entropy.

Sol.

Saturated steam $\Rightarrow x = 1$

from table at $P = 6$ bars.

$V = V_g = 0.3156\ m^3/kg$, $h = h_g = 2757\ kJ/kg$; $U = U_g = 2563\ kJ/kg$

$S = S_g = 6.761\ kJ/kg$

Ex.: Steam at 5.3 bars and 200 °C. Find the specific volume and internal energy.

Sol.

Steam at $P = 5.3$ bars. , $T = 200\,^\circ C$

from table at 5.3 bars $\Rightarrow t_s =$

$\therefore T = 200\,^\circ C > t_s =$

$\therefore$ the state is superheated steam.

By interpolation at $P = 5.3$ bars and $T = 200\,^\circ C$

$$\frac{V - 0.4252}{0.3522 - 0.4252} = \frac{5.3 - 5}{6 - 5} \Rightarrow V = 0.4033\ \frac{m^3}{kg}$$

$$\frac{U - 2644}{2640 - 2644} = \frac{5.3 - 5}{6 - 5} \Rightarrow U = 2642\ kJ/kg$$

Ex.: Determine the condition of steam in the following cases:

1 - A a pressure of 10 bars and temperature 200 °C

2 – " " " " " " Volume 0.175 m³/kg.

Sol.

1- $P = 10$ bars , $T = 200$ °C

from st. table at $P = 10$ bars $\Rightarrow t_s = 179.9$ °C

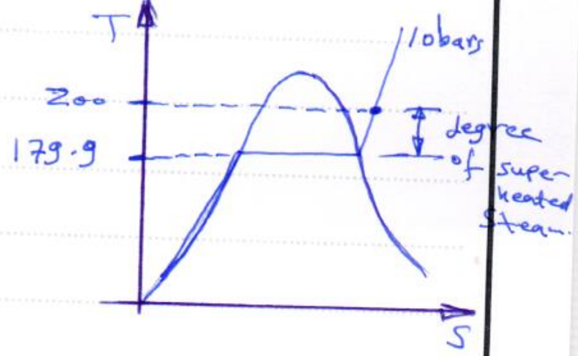
$\therefore T > t_s \Rightarrow \therefore$ the state is superheated steam.

at $P = 10$ bars

$v_g = 0.194\ m^3/kg$, $h_f = 762.6\ kJ/kg$

the degree of Superheated steam $= T - t_s$

$= 200 - 179.9 = 20.1$ °C



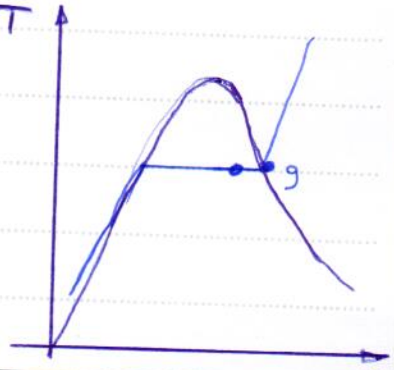
2- at 10 bars $v_g = 0.194\ m^3/kg$

$v = 0.175\ m^3/kg$ is given

$\therefore v_g > v \Rightarrow$ the state is wet steam.

$v = x * v_g \Rightarrow x = \frac{v}{v_g}$

$\therefore x = \frac{0.175}{0.194} = 0.902$



Ex.: Find the dryness fraction, the specific volume and internal energy of steam at 7 bar and enthalpy 2600 kJ/kg

Sol.

at 7 bars from steam table

$h_g = 2764$ kJ/kg , $h_f = 697$ kJ/kg

$\therefore$ $h_g > h > h_f$ $\Rightarrow$ The state is wet steam.

$h = h_f + x \cdot h_{fg} = 2600 = 697 + x * (2764 - 697)$

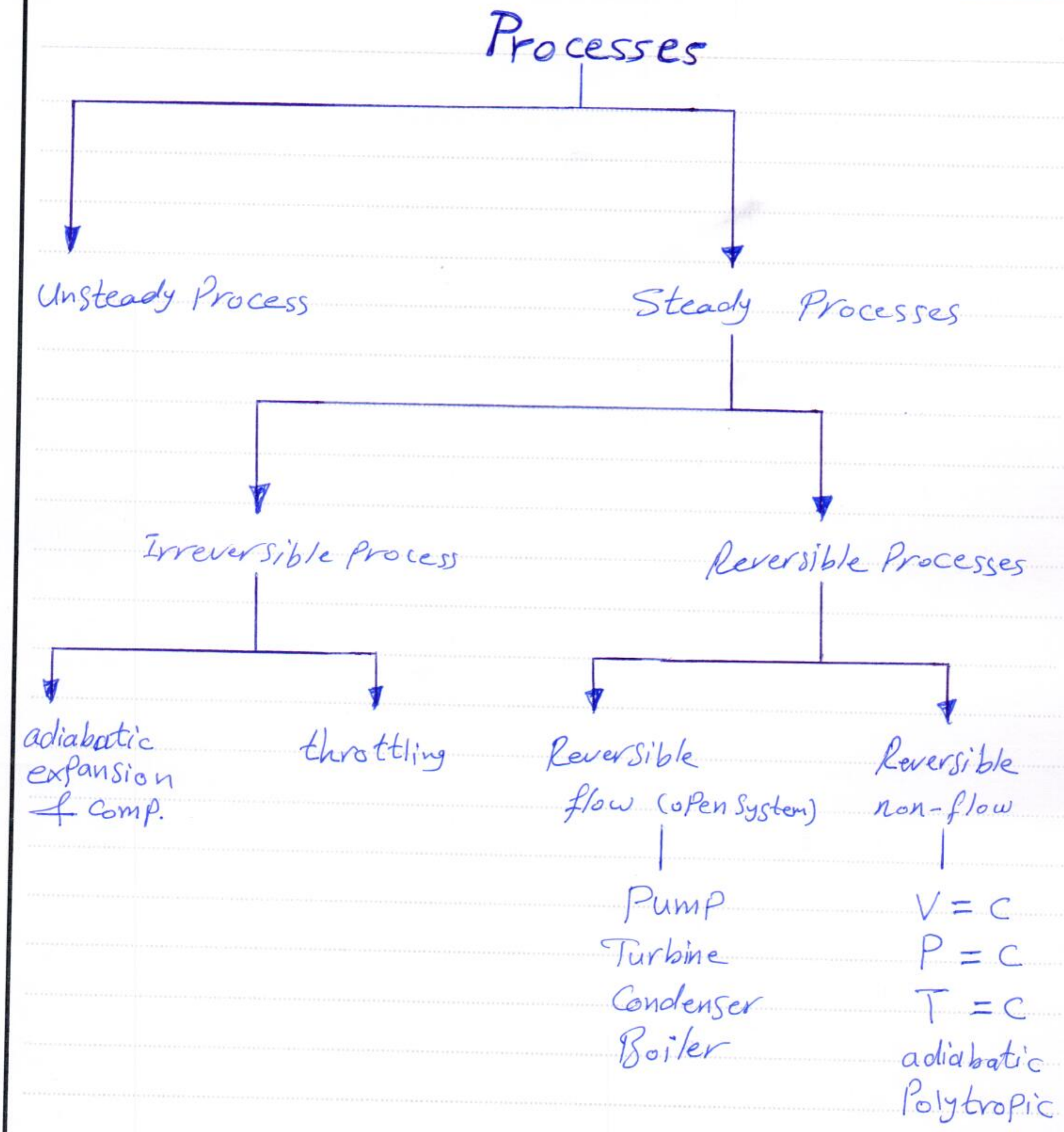
$x = 0.921$

$v = x \cdot v_g$ $\Rightarrow$ at 7 bars from s. t. $v_g = 0.2728$ m³/kg

$v = 0.921 * 0.2728 = 0.2515$ m³/kg

$u = u_f + x(u_g - u_f) = 696 + 0.921(2573 - 696)$

$= 2420$ kJ/kg


Processes
Unsteady Process
Steady Processes
Irreversible process
Reversible Processes
adiabatic expansion & comp.
throttling
Reversible flow (open system)
Reversible non-flow
Pump
Turbine
Condenser
Boiler
V = C
P = C
T = C
adiabatic
Polytropic

Reversible and Irreversible Processes :-

1. Closed System (Reversible)

A: Constant Volume Process (Isometric Process)

from non-flow energy equation

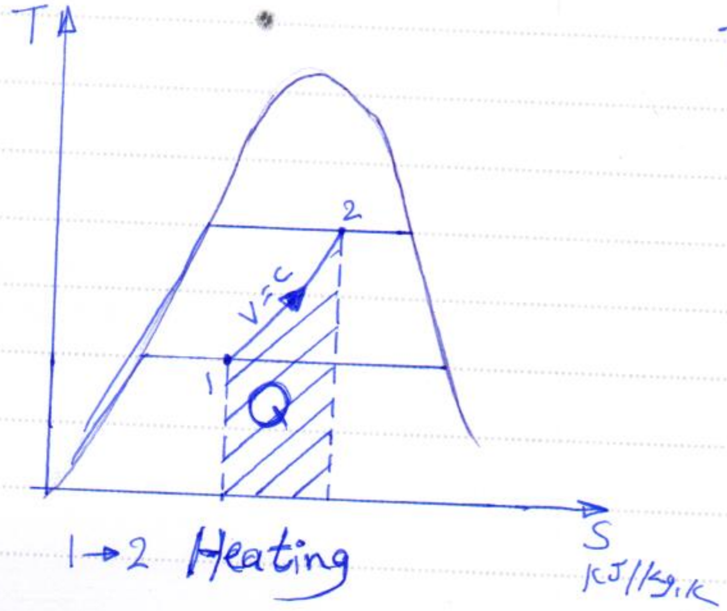
$$Q = W + \Delta U$$

$$V = c \Longrightarrow W = 0$$

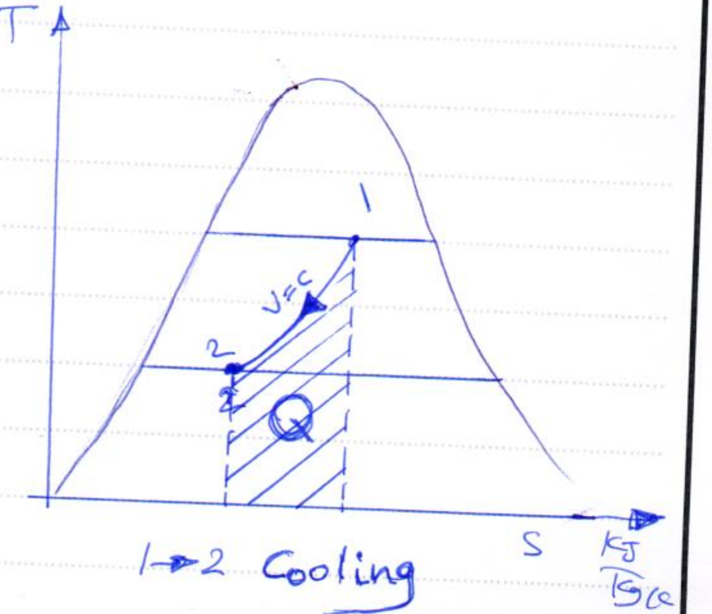
$$\therefore Q = \Delta U = U_2 - U_1$$

$$h = u + Pv$$

$$\therefore \boxed{Q = U_2 - U_1 = (h_2 - h_1) - v(P_2 - P_1)}$$



1→2 Heating



1→2 Cooling

Ex.: A vessel having a volume of 5 m³ contains 0.05 m³ of saturated liquid water and 4.95 m³ of saturated water vapour at 0.1 MPa. Heat is transfered until the vessel is fitted with saturated vapour. Determine the heat transfer for this process.

Sol.:

Condition 1 wet steam.

at 0.1 MPa = 100 kPa

$v_f = 1.0432 \times 10^{-3}$ m³/kg ; $v_g = 1.694$ m³/kg

$V = m * v \Longrightarrow m = V/v$

$\therefore m_L = \frac{V_L}{v_L} = \frac{0.05}{1.043 \times 10^{-3}} = 47.93$ kg

$m_g = \frac{V_g}{v_g} = \frac{4.95}{1.694} = 2.92$ kg

$\therefore x = \frac{m_g}{m_t} \Longrightarrow \therefore x = \frac{2.92}{50.85} = 0.0574$

$\therefore U_1 = U_{f_1} + x\,U_{fg_1}$ at 100 kPa

$U_1 = 417.36 + 0.0574 * 2088.7 = 521.8$ kJ/kg

Condition 2 V = constant , Dry saturated steam.

$v_1 = \frac{V}{m} = \frac{5}{50.85} = 0.09833$ m³/kg $= v_2$ at dry sat. st.

from steam table and at $v_2 = 0.09833$ and dry saturated we will found $U_2 = U_{g_2}$

By Interpolation

v_g	u_g
0.09963	2600.25
0.09833	u_2
0.08875	2601.98

$$\frac{u_2 - 2600.25}{2601.98 - 2600.25} = \frac{0.09833 - 0.09963}{0.08875 - 0.09963}$$

$$\Longrightarrow u_2 = 2600.465 \text{ kJ/kg}$$

$Q = W + \Delta u \quad , W = 0 \quad V = c$

$Q = u_2 - u_1 \Rightarrow Q = 2600.465 - 521.8$

$Q = 2078.665$ kJ/kg

$Q = 50.85 * 2078.665 = 105700.1$ kJ

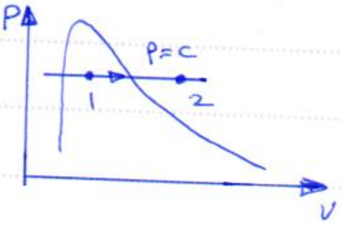
B. Constant Pressure Process :-

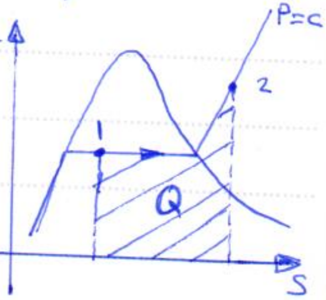
from NFEE

$Q = W + \Delta U \quad , W = \int P\,dv = P(V_2 - V_1)$

$Q = (P_2V_2 - P_1V_1) + (U_2 - U_1) = H_2 - H_1$

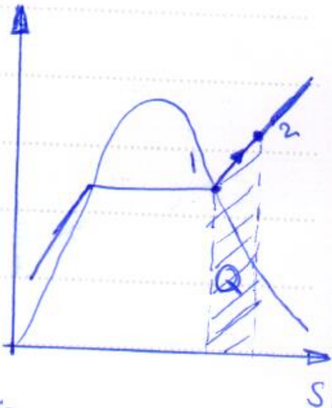
$$\therefore \boxed{Q = m(h_2 - h_1)}$$





Ex.:- 0.05 kg of a dry Saturated Steam is heated at a constant Pressure of 2 bars until the Volume occupied is 0.0658 m³. Calculate the heat supplied and the work done.

Sol.



$m = 0.05\ kg \ , x = 1 \quad P = 2\ bars = C$

Condition 1: dry sat. $x = 1$, $P = 200\,kPa$

from steam table at dry-sat. and at $P = 200\ kPa$

$h_1 = h_g = 2707\ kJ/kg \ , \ v_1 = v_{g_1} = 0.8856\ m^3/kg$

Condition 2: $P_2 = P_1 = const. \Rightarrow P_2 = 200\ kPa \ ; V_2 = 0.0658\ m^3$

$V_2 = m v_2 \Rightarrow v_2 = \frac{0.0658}{0.05} \Rightarrow v_2 = 1.316\ m^3/kg$

∴ from st. table at $P = 200\ kPa$ and $v_{g_2} = 0.8856\ m^3/kg$

$\therefore v_2 > v_{g_2} \Rightarrow$ the state is superheated st.

from St. table superheated st. at 200 kPa and $v_2 = 1.316 \frac{m^3}{kg}$

$h_2 = 3072$ kJ/kg

$Q = m(h_2 - h_1) = 0.05(3072 - 2707) = 18.25$ kJ

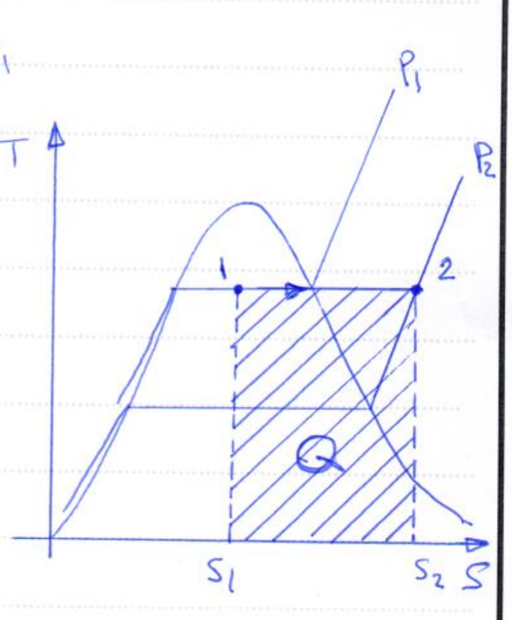
$W = mP(v_2 - v_1) = 0.05 * 200(1.316 - 0.885) = 4.304$ kJ

C. Constant temperature (Isothermal Process)

from NFEE

$Q = W + \Delta U$; $\Delta U = U_2 - U_1$

$Q = mT(S_2 - S_1)$ kJ



Ex.:

Steam at 7 bars and quality 0.9 , expands in cylinder behind a Piston isothermally and reversibly to a pressure of 1.5 bars . Calculate the change in enthalpy of steam and the heat supplied during Process and the work done, sketch (T-s).

Sol.:

Condition 1: $P_1 = 7$ bars $= 700$ kPa $x_1 = 0.9 \Rightarrow$ wet st.

from St. table at 700 kPa $T = t_s = 165$ °c

$h_{f_1} = 697$ kJ/kg ; $h_{fg_1} = 2067$ kJ/kg ; $h_1 = h_{f_1} + x_1 h_{fg_1}$

$h_1 = 697 + 0.9(2067) = 2557.3$ kJ/kg