

THERMODYNAMICS

1

**CHAPTER ONE**

*Introduction and  
Basic Concepts*



## **Thermodynamics:-**

can be defined as the science of energy. The name thermodynamics stems from the Greek words *therme* (Heat) and *dynamics* (Power).

**Applied thermodynamics:** is the science of relationship between heat, work, and the properties of the system. It is concerned with the means necessary to convert heat energy from available sources such as chemical fuels or nuclear piles into mechanical work.

## **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 substance used in thermodynamic system are air and steam.

**Pure Substance:-** Is a single substance or mixture of substance which has the same consistent composition throughout. Such as water, Nitrogen, Helium and Carbon dioxide.

In other words, it is a homogeneous substance and its molecular structure does not vary. For example, steam or water or mixture of both can be considered as a pure substance. This is because it has the same molecular or chemical structure through its mass.



## → Dimensions and Units

Any physical quantity can be characterized by "dimensions". The arbitrary magnitudes assigned to the dimensions are called "Units".

Some basic dimensions such as mass ( $m$ ), length ( $L$ ), time ( $t$ ), and temperature ( $T$ ) are selected as [primary] or fundamental dimensions, while others such as velocity ( $V$ ), energy ( $E$ ), and volume ( $V$ ), are expressed in terms of the primary dimensions and are called [secondary] dimensions, or derived dimensions.

Two sets of units are still in common use today:

1. The English System
2. System International (SI) Units

Dimension	Unit
Length	meter (m)
mass	kilogram (kg)
Time	second (s)
Temperature	Kelvin (K)
Electric current	Ampere (A)
Amount of Light	Candela (C)
Amount of matter	mole (mol)



Quantity	SI Units	from English to SI Units
Area	$m^2$	$1 \text{ ft} = 0.3048 \text{ m}$
Density	$kg/m^3$	$1 \text{ in} = 0.0254 \text{ m}$
Energy	J	$1 \text{ lbm} = 0.4536 \text{ kg}$
Energy per unit mass	J/kg	$1 \text{ Slug} = 14.594 \text{ kg}$
Force	N	$1 \text{ lbf} = 4.448 \text{ N}$
Heat Flux	$W/m^2$	
Heat transfer rate	W	$1 \text{ Btu} = 1055.06 \text{ J}$ $1 \text{ cal} = 4.1868 \text{ J}$ $1 \text{ Btu/lbm} = 2326 \text{ J/kg}$
mass flow rate	kg/s	$1 \text{ hp} = 745.7 \text{ W}$
Power	W (J/s)	
pressure & Stress	$N/m^2$	$1 \text{ lbf/ft}^2 = 47.88 \text{ N/m}^2$
Specific heat	J/kg·K	$1 \text{ psi} = 1 \text{ lbf/in}^2 = 6894.8 \text{ N/m}^2$
Surface tension	N/m	
Velocity	m/s	$1 \text{ standard atmosphere} = 1.0132 \times 10^5 \text{ N/m}^2$
Viscosity (Kin.)	$m^2/s$	
Volume	$m^3$	$1 \text{ gal} = 0.003785 \text{ m}^3$
Volume flow rate	$m^3/s$	
Specific Volume	$m^3/kg$	



## -- Heat Engine :-

is the name given to a system which by operating in a cyclic manner produces net work from a supply of heat.

## -- Heat, work, and the System :-

Heat is a form of energy which is transferred from one body to another body at a lower temperature by <sup>virtue</sup> of the temperature difference between the bodies.

Note that the heat and work are a transient quantities, not properties.

In mechanics, work is defined as the product of the force ( $F$ ) and the distance moved ( $x$ ) in the direction of the force  $\Rightarrow W = F \times x$

If a system exists in which a force at the boundary of the system is moved through a distance, then work is done by or on the system.

$$\text{Work} = \text{Force} \times \text{distance}$$

A system may be defined as a collection of matter within prescribed and identifiable boundaries.

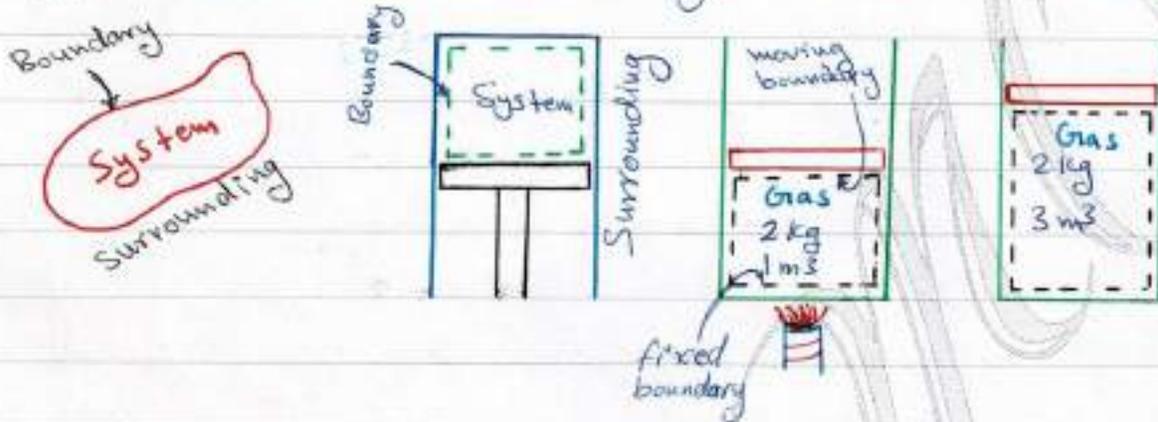
or

a quantity of matter or a region in space chosen for study.

The mass or region outside the system is called the **Surrounding**.



The real or imaginary surface that separates the System from its surrounding is called the boundary.

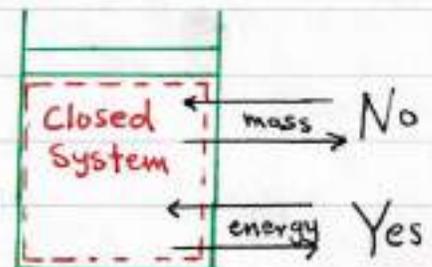


## - Closed and Open System

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 (also known as a control mass) consists of a fixed amount of mass, and no mass can cross its boundary, that is, no mass can enter or leave a closed System.

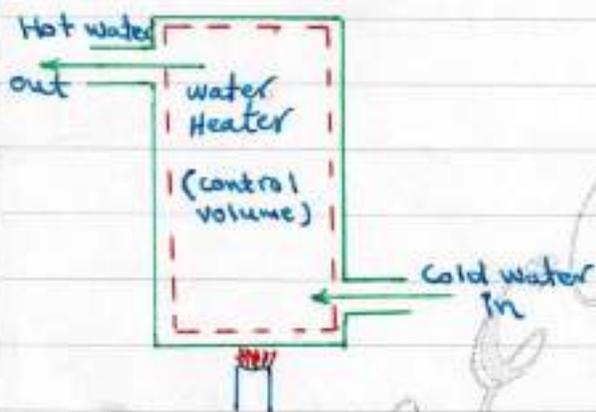
But energy in the form of heat or work, can cross the boundary, and the volume of a closed System dose not have to be fixed.



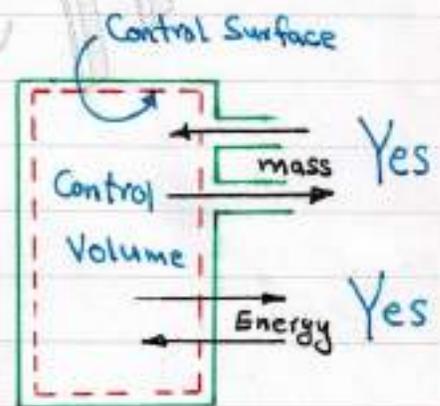


If, as a special case, even energy is not allowed to cross the boundary, that system is called an isolated system.

An Open System, or a control volume, as it is often called, is a properly selected region in space. It usually encloses a device that involves mass flow, such as a compressor, turbine, or nozzle. Both mass and energy can cross the boundary of a control volume which is called a control surface.



[ An open system (a control volume) with one inlet and one exit ]



[ Both mass and energy can cross the boundaries of a control volume ]



## - 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  $m$ .

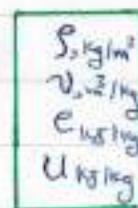
The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.

Not all properties are independent, some are defined in terms of other ones, such as density ( $\rho$ ), Specific volume ( $v$ ), Specific gravity ( $S_g$ ).

Properties are considered to be either **intensive** or **extensive**.

**Intensive** properties are those that are independent of the 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 ( $E$ ).

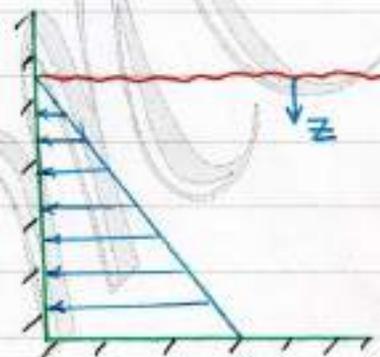
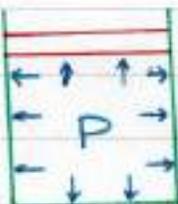
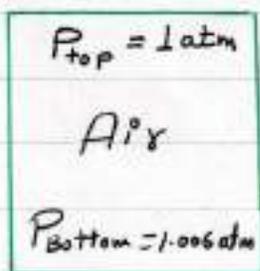


Intensive properties are independent of the size of System



## -. Pressure :-

is the force exerted by a fluid per unit area. We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is Stress.



In a container filled with a gas the variation of pressure with height is negligible

The pressure of a fluid at rest increases with depth (as a result of added weight)

Since pressure is defined as force per unit area, it has the unit of newtons per square meter ( $\text{N/m}^2$ ), which is called a pascal (Pa).

$$P = F/A$$

$$1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$$

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

$$1 \text{ MPa} = 10^6 \text{ Pa}$$

$$1 \text{ kPa} = 10^3 \text{ Pa}$$



Two other common pressure units are bar and standard atmosphere :

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

$$1 \text{ atm} = 101325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

In the English System, the pressure unit is [pound-force per square inch]  $\text{lbf/in}^2$  or  $\text{psi}$

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

the actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum, i.e., absolute zero pressure.

the difference between the absolute pressure and the local atmospheric pressure is called the gage pressure.

pressures below atmospheric pressure are called vacuum pressure, and are measured by vacuum gage.

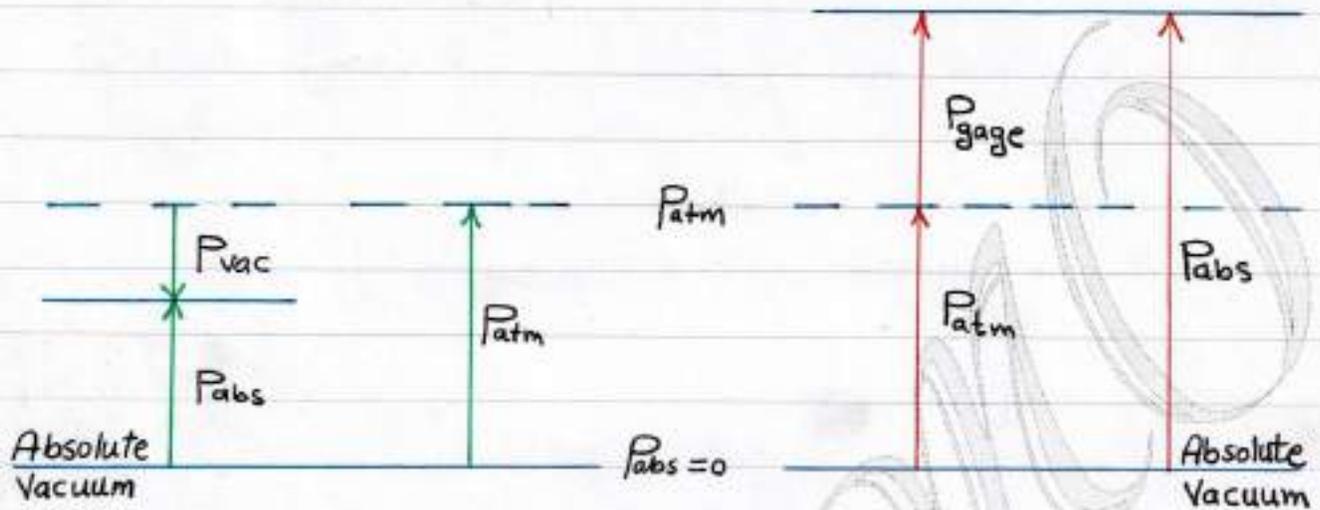
Absolute, gage, and vacuum pressure are all positive quantities and are related to each other by:

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

(For pressure above  $P_{\text{atm}}$ )

$$P_{\text{vac.}} = P_{\text{atm}} - P_{\text{abs}}$$

( " " below " )



**Ex:** A vacuum gage connected to a chamber reads 5.8 psi at a location where the atmospheric pressure is 14.5 psi.  
Determine the absolute pressure in the chamber.

**Sol:**

$$\begin{aligned} P_{abs} &= P_{atm} - P_{vac} \\ &= 14.5 - 5.8 \\ &= 8.7 \text{ psi} \end{aligned}$$

**Ex:** The piston of a piston-cylinder device containing a gas has a mass of 60 kg and a cross-sectional area of 0.04 m<sup>2</sup>, as shown below. The local atmospheric pressure is 0.97 bar and the gravitational acceleration is 9.8 m/s<sup>2</sup>.

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



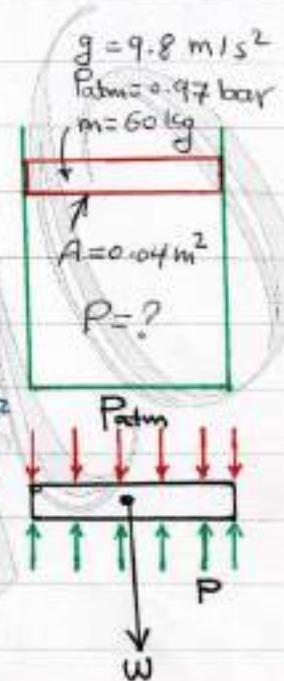
Sol: a. Equilibrium  $\Rightarrow \Sigma F = 0$

$$P \cdot A = P_{atm} \cdot A + W \quad \rightarrow w = mg$$

$$P = P_{atm} + \frac{mg}{A}$$

$$= 0.97 \text{ bar} + \frac{60 \text{ kg} \cdot 9.8 \frac{\text{m}}{\text{s}^2}}{0.04 \text{ m}^2} \cdot \frac{1 \text{ N}}{1 \text{ kg} \cdot \frac{\text{m}^2}{\text{s}^2}} \cdot \frac{1 \text{ bar}}{10^5 \text{ N/m}^2}$$

$$= 1.117 \text{ bars}$$



## - Temperature

Although we are familiar with temperature as a measure of "hotness" or "coldness" it is not easy to give an exact definition for it.

Based on our physiological sensations, we express the level of temperature qualitatively with words like freezing cold, cold, warm, hot, and red-hot.

The variation of an easily measurable property of a substance with temperature can be used to provide a temperature-measuring instrument. For example, the length of a column of mercury will vary with temperature due to the expansion and contraction of the mercury or another liquid, gas, and solid.



## - Temperature Scales

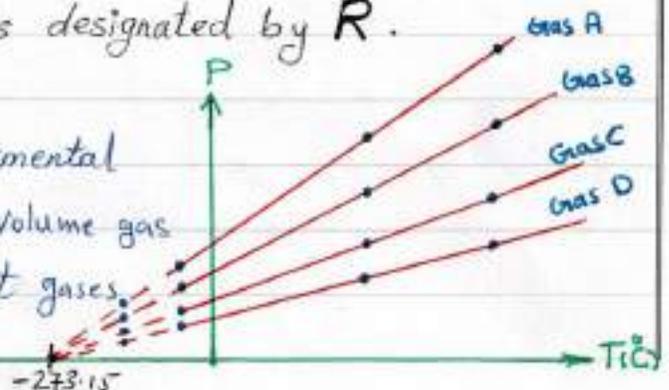
The temperature scales used in the SI and in the English System today are the **Celsius Scale** (formerly called the **Centigrade scale**) and the **Fahrenheit Scale**.

On the Celsius scale, the ice and Steam point, are assigned the values of  $0$  and  $100^{\circ}\text{C}$ , respectively, the corresponding values on the Fahrenheit scale are  $32$  and  $212^{\circ}\text{F}$ .

In thermodynamics, it is very desirable to have a temperature scale that is independent of the properties of any substance or substances. The thermodynamic temperature scale in the SI is the **Kelvin scale**. The temperature unit on this scale is the Kelvin, which is designated by **K** (not  $^{\circ}\text{K}$ ). The lowest temperature on the Kelvin scale is  $0, \text{K}$ .

The thermodynamic temperature scale in the English system is the **Rankine scale**, the temperature unit on this scale is the rankine, which is designated by **R**.

[P versus T plots at the experimental data obtained from a constant-volume gas thermometer using four different gases at different pressures]





$$T(K) = T(^{\circ}C) + 273.15$$

$$T(R) = T(^{\circ}F) + 459.67$$

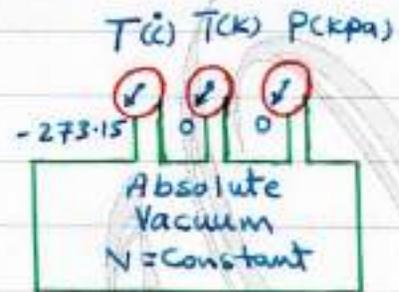
$$T(R) = 1.8 T(K)$$

$$T(^{\circ}F) = 1.8 T(^{\circ}C) + 32$$

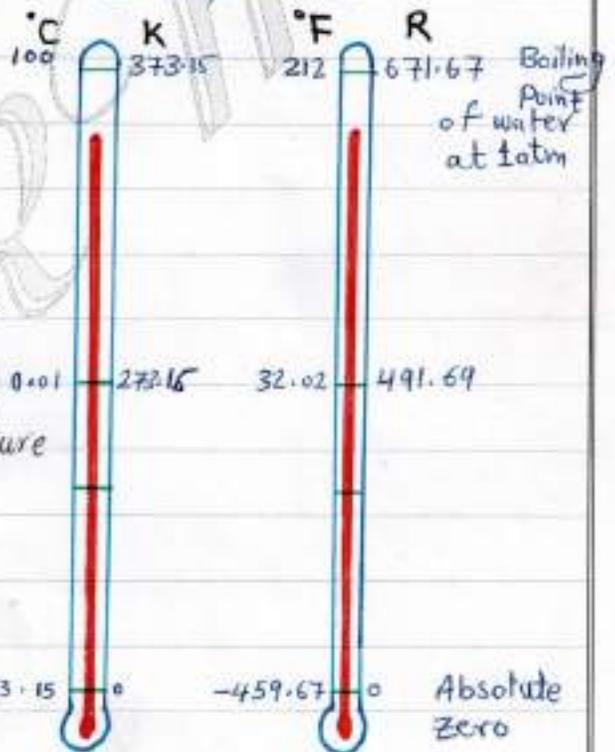
$$\Delta T(R) = 1.8 \Delta T(K)$$

$$\Delta T(K) = \Delta T(^{\circ}C)$$

$$\Delta T(R) = \Delta T(^{\circ}F)$$



A constant-volume gas thermometer would read  $-273.15$  at absolute zero pressure



**Ex:** During a heating process, the temperature of a system rises by  $10^{\circ}C$ . Express this rise in temperature in K, F, and R.

**Sol:**

$$\Delta T(K) = \Delta T(^{\circ}C) = 10^{\circ}C$$

$$\Delta T(R) = 1.8 \Delta T(K)$$

$$= 1.8 \times 10 = 18 R$$

$$\Delta T(^{\circ}F) = \Delta T(R) = 18^{\circ}F$$

Comparison of temperature scales

قال رسول الله صلى الله عليه وسلم: من دبر علمه حتى يفرغ من الدنيا فله فيها حظا كبيرا  
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## Volume

Volume is a property, being that property which is associated with cubic measure.

The unit of volume is the cubic meter ( $m^3$ ). Sometimes the liter L may be used.

$$1 \text{ Liter} = 1 \text{ Cubic decimeter} \quad (1 \text{ dm}^3 = [10^{-1} \text{ m}]^3)$$

If the volume of a substance increases then the substance is said to have been **Expanded**.

If the volume of a substance decreases then the substance is said to have been **Compressed**.

Specific volume is given the symbol ( $v$ )

$$v = \frac{V}{m} \quad m^3 / kg$$

$v \equiv$  It is the reciprocal of density and is defined as the volume per unit mass.

Density defined as mass per unit volume.

$$\rho = \frac{m}{V} \quad kg / m^3$$



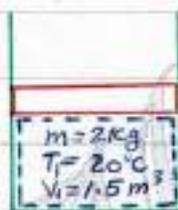
Specific gravity or relative density :

is defined as the ratio of the density of a substance to the density of some standard substance at specified temperature, [usually water at 4°C] for which  $\rho_{H_2O} = 1000 \text{ kg/m}^3$

$$\rho_s = \frac{\rho}{\rho_{H_2O}}$$

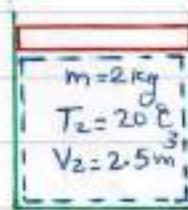
State and Equilibrium :

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. State 1

A system at two different States



b. State 2

thermodynamics deals with equilibrium states. The word equilibrium implies a state of balance. In an equilibrium state, there are no unbalanced potentials (or driving forces) within the system.



## Types of Equilibrium:

➤ **Thermal equilibrium:** If the temperature is the same throughout the entire system, then the system is in thermal equilibrium.

20°C	23°C
30°C	
35°C	40°C
42°C	

a. Before

32°C	32°C
32°C	
32°C	32°C
32°C	

b. After

A closed system reaching thermal equilibrium

➤ **Mechanical Equilibrium:** is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

➤ **Phase Equilibrium:** If a system involves two phases, it is phase equilibrium when the mass of each phase reaches an equilibrium level and stays there.

➤ **Chemical Equilibrium:** A system is in chemical equilibrium if its chemical composition does not change with time (no chemical reactions occur).

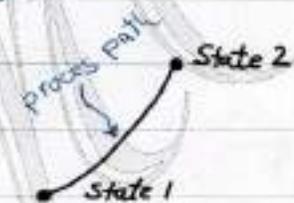
A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.



## Processes and Cycles:

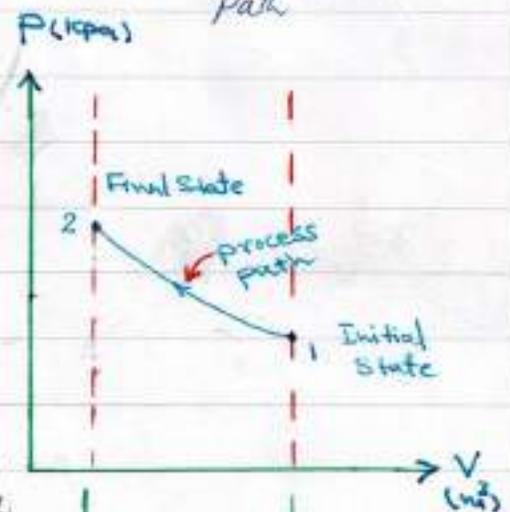
Any change that a system undergoes from one equilibrium state to another is called a **Process**, and the series of states through which a system passes during a process is called the **Path** of the process.

Process diagrams that plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.



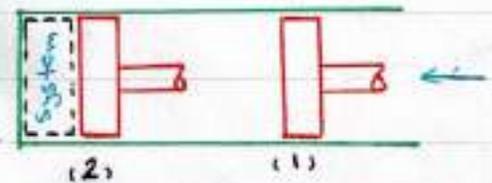
A process between States 1 and 2 and the process path

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 temperature  $T$  remains constant.



The P-V diagram of a compression process



An **isobaric** process is a process during which the pressure  $P$  remains constant.

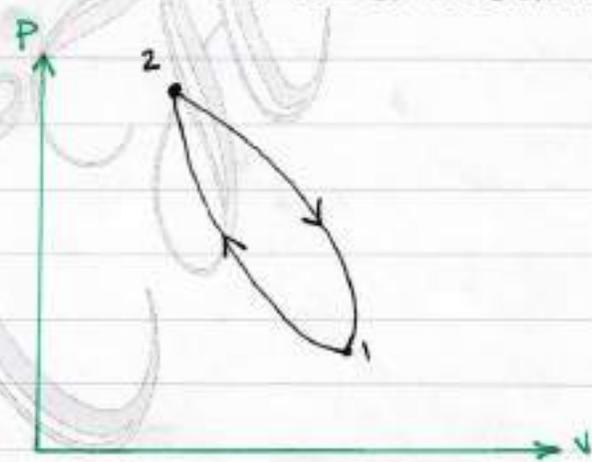
An **isochoric** (or **isometric**) process is a process during which the specific volume  $v$  remains constant.

A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.

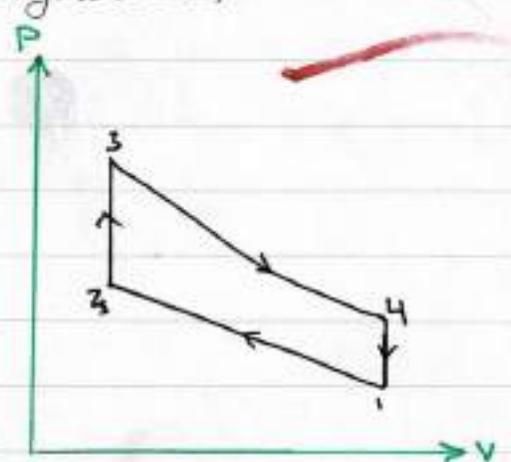
### \* Types of thermal Cycle \*

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 (I.C.E).



a- A two-process cycle



b- A Four-process cycle



## - 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 created or destroyed.

## = Forms of Energy :-

Energy can exist in numerous forms such as thermal, mechanical, kinetic, Potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the Total Energy "E" of a System. The total energy of a System on unit mass basis denoted by "e" and is defined as :-

$$e = \frac{E}{m} \quad \text{Jg / kg}$$

$\frac{\text{Jg}}{\text{kg}}$

In thermodynamics analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups :-

1. Microscopic

2. Macroscopic

the microscopic forms of energy are those related to the molecular structure of a System and the degree



of the molecular activity, and they are independent of outside reference frames.

The sum of all the microscopic forms of energy is called the "Internal Energy" of a System and is denoted by "U"

$$U = m \cdot u \quad \text{kJ}$$

$m \equiv$  mass kg

$u \equiv$  Specific internal energy kJ/kg

The macroscopic energy of a System is related to motion and the influence of some external effect such as gravity, magnetism, electricity, and surface tension.

the energy that a system possesses as a result of its motion relative to some reference frame is called "Kinetic Energy" KE

$$dE = F \cdot dx$$

$$\int dE = \int F \cdot dx$$

$$F = m \cdot a = m \cdot \frac{dc}{dt}$$

$c =$  velocity

$t =$  time





$$\int dE = \int m \cdot \frac{dc}{dt} \cdot dx$$

$$\int dE = m \int \frac{dx}{dt} \cdot dc, \quad \frac{dx}{dt} = c$$

$$= m \int c \, dc$$

$$\int_0^E dE = m \int_{c_1}^{c_2} c \, dc$$

$$= m \left[ \frac{c^2}{2} \right]_{c_1}^{c_2}$$

$$K.E = \frac{1}{2} m (c_2^2 - c_1^2), \quad c_1 = 0, \quad E \equiv K.E$$

$$K.E = \frac{1}{2} m c_2^2 \quad \text{kJ}$$

or, on a unit mass basis (Specific Kinetic energy)

$$k.e = \frac{c^2}{2} \quad \text{kJ/kg}$$

- Single phase Point (Triple Point) of water:

The state in which the solid, liquid and vapor exist together.



The energy that a System possesses as a result of its elevation in a gravitational field is called **Potential Energy "PE"** and is expressed as:

$$PE = W \cdot Z$$

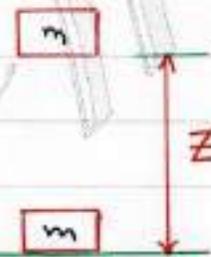
$$= mgZ \text{ Jole (N.m)}$$

or, on a unit mass basis, (Specific potential energy)

$$Pe = gZ \text{ kg/kg}$$

$g \equiv$  gravitational acceleration.

$Z \equiv$  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"**.

$$F.E = P \cdot V$$

**Heat Energy**  $\therefore$  It is one form of energy that produced only when Temperature difference between the System and Surrounding. There are three types of Heat transfer  $\therefore$

1. Conduction
2. Convection
3. Radiation

Heat energy is given the symbol " $Q$ ", to indicate a rate of heat transfer, a dot is placed over the symbol  $Q$ , thus

$$\dot{Q} = \text{heat transfer / unit time}$$

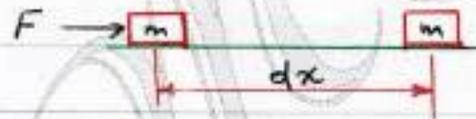


## - Work Energy: is

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

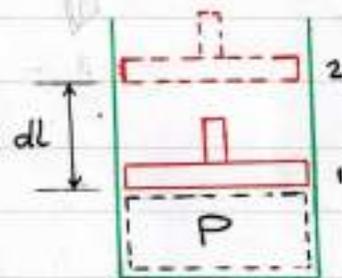
$$dW = F \cdot dL, F = P \cdot A$$

$$= P \cdot A \cdot dL, dv = A \cdot dL$$



$$\int_1^2 dW = \int_{v_1}^{v_2} P \cdot dv$$

$$W_{1-2} = \int_{v_1}^{v_2} P \cdot dv$$



$$W_{1-2} = \int_{v_1}^{v_2} P \cdot dv$$

Power: is the rate of doing work.

$$\text{power} = \frac{\text{work done}}{\text{Time taken}} = \frac{\text{Joule}}{\text{second}}$$

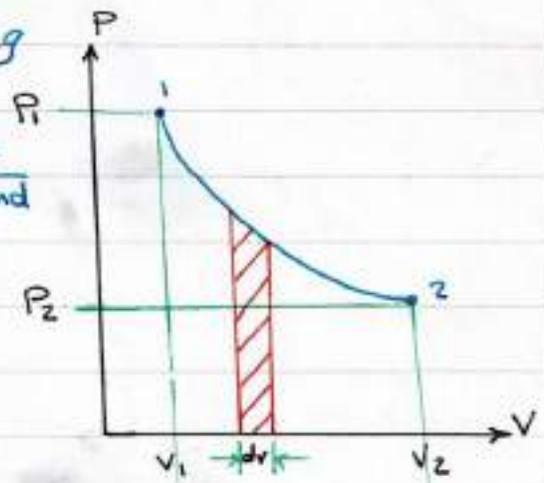
$$P = \frac{W}{t} \quad \text{J/s} \equiv \text{Watt}$$

$$\text{Power} = w \cdot \dot{m}$$

$$\equiv \frac{\text{kg}}{\text{s}} \cdot \frac{\text{kg}}{\text{s}} = \frac{\text{kg}^2}{\text{s}^2} = \text{kW}$$

$$\dot{m} \equiv \text{flow rate} = \rho CA$$

$$\rho: \text{density (kg/m}^3), C: \text{velocity (m/s)}, A: \text{Area (m}^2)$$



$W = \text{Area under the curve}$



## - Spring Work :

$$dW = F \cdot dx \quad \dots \textcircled{1}$$

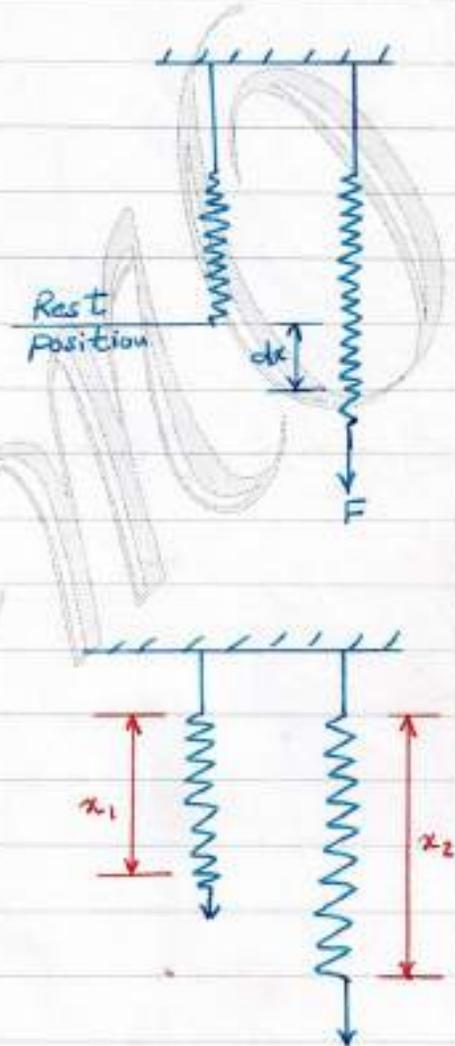
$$F = K \cdot x \quad \dots \textcircled{2}$$

$K \equiv$  Spring Constant (kN/m)

Sub eqn (2) in (1)

$$\int dw = \int_{x_1}^{x_2} K \cdot x \cdot dx$$

$$W_{\text{spring}} = \frac{1}{2} K (x_2^2 - x_1^2)$$



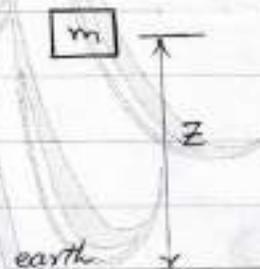
~~linear~~



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

**Sol:**

$$\begin{aligned} P.E &= mgz \\ &= 2 \times 9.81 \times 3500 \times 10^{-3} \\ &= 68.67 \text{ kJ} \end{aligned}$$



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

**Sol:**

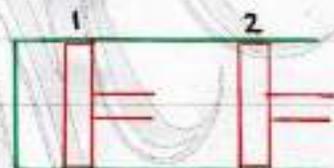
$$\begin{aligned} W &= \int_{x_1}^{x_2} F \cdot dx \\ &= \int_1^4 kx^2 dx \\ &= k \int_1^4 x^2 dx \\ &= k \left[ \frac{x^3}{3} \right]_1^4 = \frac{133}{4 \times 3} [4^3 - 1^3] \\ &= 69825 \text{ N.m} \\ &= 69.825 \text{ kJ} \end{aligned}$$

$$\begin{aligned} F &\propto x^2 \\ F &= k \cdot x^2 \\ 133 &= k(2)^2 \\ \therefore k &= \frac{133}{4} \text{ N/m}^2 \end{aligned}$$



**Ex:** Let the pressure in the cylinder in the figure given by the equation  $P = c/V$  as a function of Volume.

- find the work done, if the initial pressure is 400 kpa, the initial volume  $0.02 \text{ m}^3$  and the final volume is  $0.08 \text{ m}^3$
- Is the sign correct?



**Sol:** a.  $P = c/V \Rightarrow P_1 V_1 = P_2 V_2$

$$W = \int_{V_1}^{V_2} P \cdot dV = \int_{V_1}^{V_2} \frac{c}{V} dV = c \int_{V_1}^{V_2} \frac{dV}{V}$$

$$W = P_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V} = P_1 V_1 [\ln V]_{V_1}^{V_2} = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$W = 400 \times 0.02 \times \ln(0.08/0.02) = 11.09 \text{ kJ}$$



- the sign correct since it is positive and the work is done by the system.

**Ex:** The pressure in the cylinder shown below varies in the following manner with volume  $P = c/V^2$ , if the initial volume is  $0.05 \text{ m}^3$  and the final pressure is 200 kpa, find the work done by the system?

**Sol:**

$$W = \int_{V_1}^{V_2} P \cdot dV = \int_{V_1}^{V_2} \frac{c}{V^2} dV$$



initial pressure = 500 kpa,



$$W = C \left[ \frac{1}{V_1} - \frac{1}{V_2} \right]$$

$$C = P_1 V_1^2 = P_2 V_2^2 \Rightarrow V_2 = V_1 \left( \frac{P_1}{P_2} \right)^{1/2}$$

$$\begin{aligned} W &= P_1 V_1 - P_2 V_2 \\ &= P_1 V_1 - (P_2 P_1)^{1/2} V_1 \end{aligned}$$

$$= 500 \times 0.05 - (500 \times 200)^{1/2} \times 0.05$$

$$= 9.19 \text{ k N.m} = 9.19 \text{ kJ} \quad +ve \text{ work done by the System}$$

**Ex:** A fluid in a cylinder is at a pressure of  $700 \text{ k N/m}^2$ . It is expanded at constant pressure from a volume of  $0.28 \text{ m}^3$  to a volume of  $1.68 \text{ m}^3$ . Determine the work done?

**Sol:**

$$\begin{aligned} \text{Work done} = W &= P(V_2 - V_1) \\ &= 700 \times 10^3 (1.68 - 0.28) \\ &= 7 \times 10^5 \times 1.4 \\ &= 0.98 \text{ MJ} \end{aligned}$$

Hand  
1500



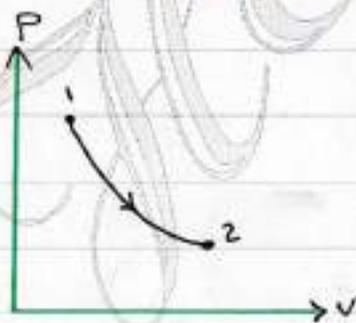
## - Reversibility

A more rigorous definition of reversibility is as follows: When a fluid undergoes a reversible process, both the fluid and its surroundings can always be restored to their original state. The criteria of reversibility are as follows:

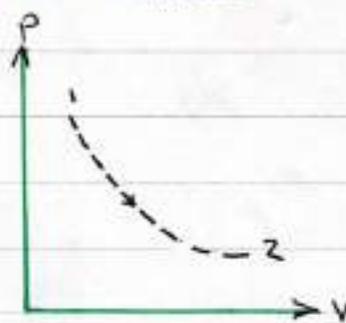
1. The process must be frictionless.
2. The difference in pressure between the fluid and its surroundings during the process must be infinitely small.
3. The difference in temperature between the fluid and its surroundings during the process must be infinitely small.

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

An irreversible process is usually represented by a dotted line joining the end states to indicate that 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,
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.

## - 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 walls.

$$\text{work done by fluid} = (PA) \cdot dL \\ = P dV$$

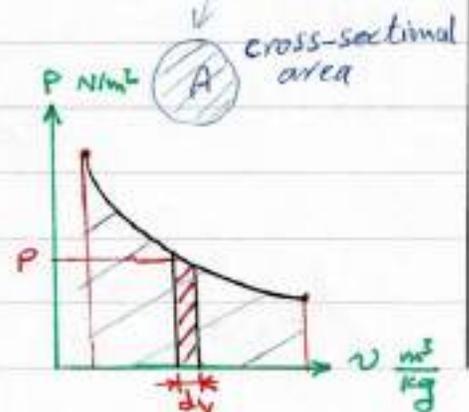
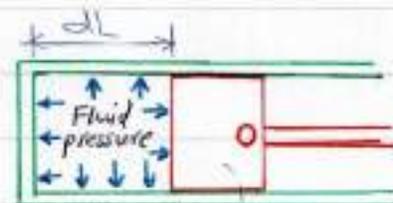
Per unit mass

$$\text{Work done} = P dv$$

(where  $v$  is the specific volume)

w:

$$\text{work done} = \text{shaded area} \\ = \int_1^2 p dv$$





## - The zeroth Law (law number zero) :-

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 equi.



thermal equi.



If  $T_A = T_B$

$$T_A = T_C$$

Also thermal equilibrium

$$\therefore T_B = T_C \quad (\text{thermal equilibrium})$$

## - The first Law of thermodynamics :-

The concept of energy and the hypothesis that it can be neither created nor destroyed were developed by scientists in the early part of the nineteenth century, and became known as the Principle of the Conservation of Energy. The First Law of Thermodynamics is merely one statement of this general principle with particular reference to heat energy and mechanical energy (work).

The First Law of Thermodynamics can be stated as follows:



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

$$\begin{aligned} \dot{Q} &= \dot{q}_{in} & \dot{W} &= \dot{w}_{in} \\ \sum dQ &= \sum dW & \sum dq &= \sum dw \end{aligned}$$

kW  
kJ/kg cycle

where  $\sum$  represents the sum for a complete cycle.

**Ex:10** In a certain steam plant the turbine develops 1000 kW, the heat supplied to the steam in the boiler is 2800 kJ/kg, 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 steam flow in  $\frac{kg}{s}$ .

**Sol:10**

$$\begin{aligned} \sum dQ &= 2800 - 2100 = 700 \text{ kJ/kg} \\ \sum dW &= 1000 - 5 = 995 \text{ kW} \end{aligned}$$

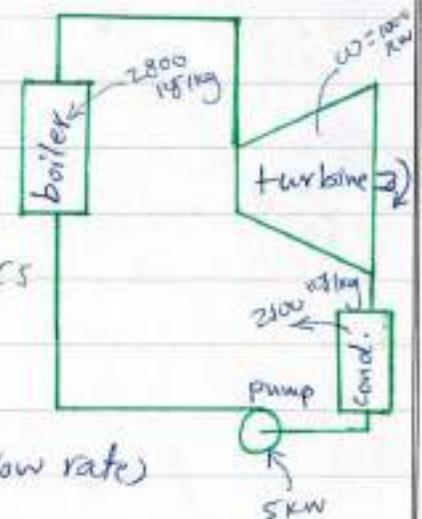
$$Q = \dot{m} q$$

from the first law of thermodynamics

$$\sum Q = \sum W$$

$$\dot{m} \cdot 700 = 995$$

$$\text{or } \dot{m} = 1.421 \text{ kg/s (Steam flow rate)}$$





## - The Steady-flow energy equation :- (SFEE),

This equation is a mathematical statement of the 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 :-

a. Potential Energy :  $P.E = m g z$  kg

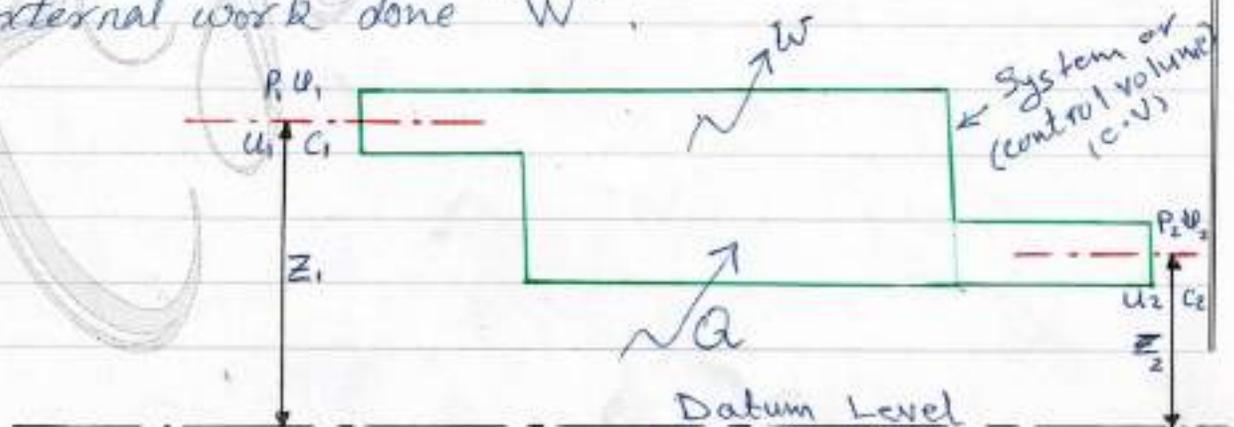
b. Kinetic Energy :  $K.E = \frac{1}{2} m C^2$  kg

c. Internal Energy :  $U = m \cdot u$  kg

d. Flow or displacement Energy :-  $F.E = P \cdot V$  kg

e. Heat received or rejected "Q".

f. External work done "W".





Applying the principle of conservation of energy to the system (or C.V.), 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 mass :-

$$gz_1 + u_1 + P_1 v_1 + \frac{1}{2} C_1^2 + q = gz_2 + u_2 + P_2 v_2 + \frac{1}{2} C_2^2 + w$$

or

$$gz_1 + \overbrace{(u_1 + P_1 v_1)}^{h_1} + \frac{1}{2} C_1^2 + q = gz_2 + \overbrace{(u_2 + P_2 v_2)}^{h_2} + \frac{1}{2} C_2^2 + w$$

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

"Steady flow Energy Equation", SFEE

h = Enthalpy

where q & w per unit mass.

Mass flow rate  $\dot{m}$

$$\dot{m} = \frac{CA}{v} = \rho CA, \quad \dot{m}_1 = \dot{m}_2$$

\* This equation is known as the continuity of mass equation.  $\dot{m} = \frac{C_1 A_1}{v_1} = \frac{C_2 A_2}{v_2}$



- 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 steady 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:

$$gz_1 + u_1 + Pv_1 + \frac{1}{2}C_1^2 + q = gz_2 + u_2 + Pv_2 + \frac{1}{2}C_2^2 + W$$

$$u_1 + q = u_2 + W$$

$$q - W = u_2 - u_1 \quad \text{"NFEE" per 1 kg}$$

When,  $\Delta Z, \Delta C^2 \approx 0 \Rightarrow$

$$q - W = h_2 - h_1 \quad \text{"SFEE" per 1 kg}$$



## - Some Applications of the SFEE :

### 1. Steam Boilers:

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

in boiler  $\therefore$  1.  $w = 0$

2.  $C_2^2 - C_1^2 / 2$  very small

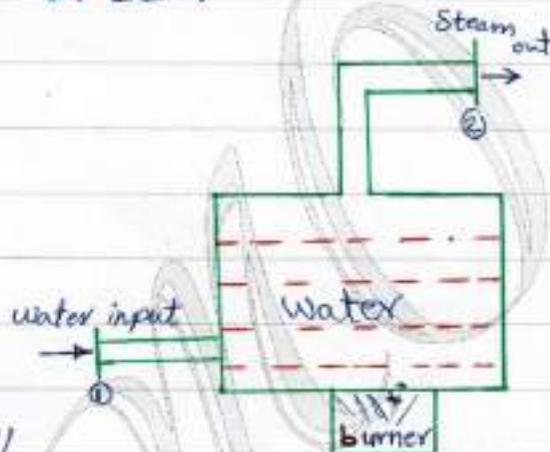
3.  $\Delta Z \approx 0$

$$\therefore q = h_2 - h_1 \quad \text{kg/kg}$$

$$\dot{Q} = \dot{m}_s (h_2 - h_1) \quad \text{kg/s (kW)}$$

$\dot{m}_s =$  Steam flow rate kg/s

$$\dot{m}_s = \rho CA$$



### 2. Turbine:

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

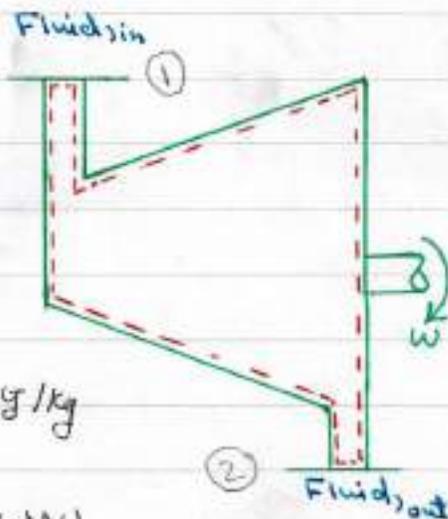
in turbine  $\therefore$  1.  $Q = 0$

2.  $C_2^2 - C_1^2 / 2 \approx 0$

3.  $\Delta Z \approx 0$

$$\therefore h_1 = h_2 + w \Rightarrow w = h_1 - h_2 \quad \text{kg/kg}$$

$$\dot{W} = \dot{m}_s (h_1 - h_2) \quad \text{kg/s (kW)}$$





## - Heat Exchanger :

in H.E. :

1.  $W=0$
2.  $C_2^2 - C_1^2 / 2 \approx 0$  (neglect)
3.  $\Delta Z \approx 0$

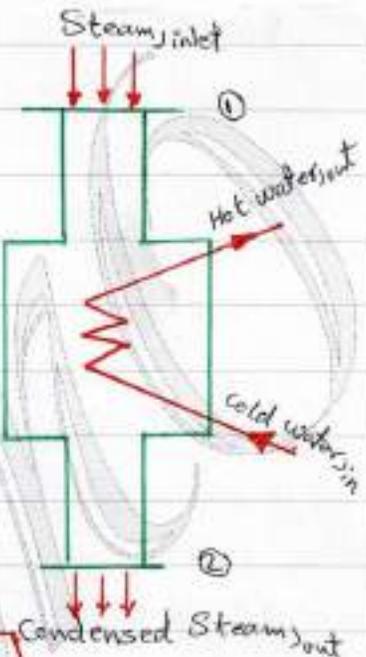
from SFEE :

$$\therefore q = h_2 - h_1 \quad (\text{rejected heat})$$

$$\dot{Q} = \dot{m}_s (h_2 - h_1)$$

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

$\dot{m}_s$  = Steam flow rate ,  $\dot{m}_w$  = cooling water flow rate  
 $c_{pw}$  = Specific Heat of water at constant pressure  
 $T_{wout}$  = outlet water Temperature.  
 $T_{win}$  = inlet " " " "



## - Nozzle :

in Nozzle : 1.  $Q=0$     2.  $W=0$     3.  $\Delta Z=0$

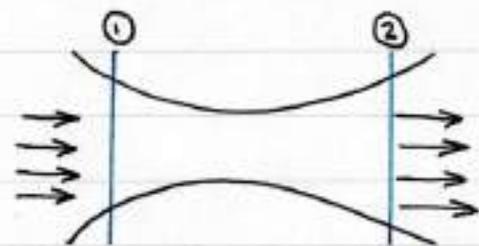
from SFEE :

$$\frac{C_2^2}{2} - \frac{C_1^2}{2} = h_1 - h_2$$

When  $C_1 \approx 0$

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

$$C_2 = \sqrt{2(h_1 - h_2)} \quad \text{m/s}$$





## - Specific Heats: 0

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

$$Q = m \cdot C \cdot \Delta T \quad \text{kJ}$$

$C$  = Specific heat capacity  $\text{kJ/kg} \cdot \text{K}$

$m$  = mass of substance.

$Q$  = heat transferred to produce temperature change.

In general, the energy required to raise the temperature will depend on how the process is executed. In thermodynamics, we are interested in two kinds of specific heats:

1. Specific heat at constant volume " $C_v$ ".
2. " " " " Pressure " $C_p$ ".

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  $C_p$ .



This is illustrated in fig. below. 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 this expansion work must also be supplied to the system.

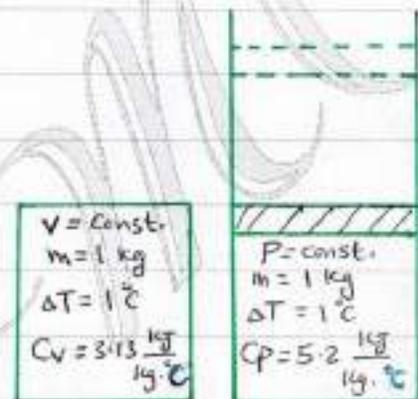
$$\therefore Q = m C \Delta T$$

for unit mass

$$q = C \Delta T$$

$$dq = C dT$$

$$\therefore C = \frac{dq}{dT}$$



( $C_v$  &  $C_p$  values of helium)

1. at constant volume:○

from NFEE:

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

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

$$C_v = \frac{dq}{dT} = \frac{du}{dT} \Rightarrow du = C_v dT \Rightarrow \Delta u = C_v \Delta T$$

∴ at constant volume

$$Q = \Delta U = m C_v \Delta T$$



## 2. at Constant Pressure: $\circ$

$$W = P_2 V_2 - P_1 V_1$$

$$q = W + \Delta U$$

$$q = (P_2 V_2 - P_1 V_1) + (U_2 - U_1)$$

$$q = (P_2 V_2 + U_2) - (P_1 V_1 + U_1)$$

$$q = h_2 - h_1$$

$$q = \Delta h$$

$$dq = dh$$

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

$$dh = C_p \cdot dT$$

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

$$Q = \Delta H = m C_p \Delta T$$

Notes: 1. Heat received by the System  $q$  is +ve  
" rejected " " "  $q$  is -ve

2. Work done by the System  $W$  is +ve  
" " on " "  $W$  is -ve



Ex: A certain fluid at 10 bar is contained in a cylinder behind a piston, the initial volume being  $0.05 \text{ m}^3$ . Calculate the work done by the fluid when it expands reversibly:

- at constant pressure to a final volume of  $0.2 \text{ m}^3$ .
- According to a linear law to a final volume of  $0.2 \text{ m}^3$  and a final pressure of 2 bar.
- According to a law  $pV = c$  to a final volume of  $0.1 \text{ m}^3$ .
- According to a law  $pV^2 = c$  to a final volume of  $0.06 \text{ m}^3$ .
- According to a law  $p = (A/V^2) - (B/V)$  to a final volume of  $0.1 \text{ m}^3$  and final pressure of 1 bar, A & B are constant.

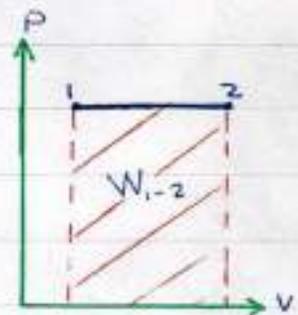
Sol:

a.

$$W = \int_1^2 p \, dV, \quad p = c$$

$$= p_1 \int_1^2 dV = p_1 [V]_1^2 = p(V_2 - V_1)$$

$$= 10 \times 10^2 (0.2 - 0.05) = 150 \text{ kJ}$$



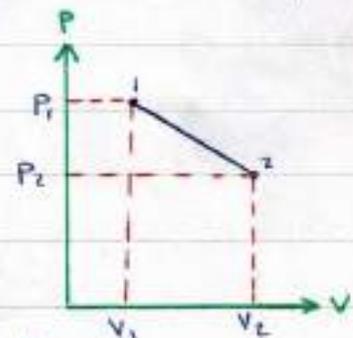
b.

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

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

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

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



1000



$$w = \int p \, dV = \int_{0.15}^{0.2} \frac{190 - 800V}{0.15} \, dV = \left[ \frac{190V - 400V^2}{0.15} \right]_{0.15}^{0.2}$$

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

c.  $PV = C \Rightarrow 10 \times 10^2 \times 0.05 = C \therefore C = 50$   
 $\therefore P = 50/V$

$$w = \int p \, dV = \int_{0.05}^{0.1} 50 \frac{dV}{V} = 50 \ln V \Big|_{0.05}^{0.1}$$

$$= 50 \{ \ln 0.1 - \ln 0.05 \}$$

$$= 34.65 \text{ kJ}$$

d.  $PV^3 = C$

$$10 \times 10^2 (0.05)^3 = C \Rightarrow C = 0.125 \Rightarrow P = \frac{0.125}{V^3}$$

$$w = \int p \, dV = \int_{0.05}^{0.1} 0.125 \frac{dV}{V^3} = \left[ 0.125 \times \frac{-1}{2V^2} \right]_{0.05}^{0.1}$$

$$w = 7.638 \text{ kJ}$$

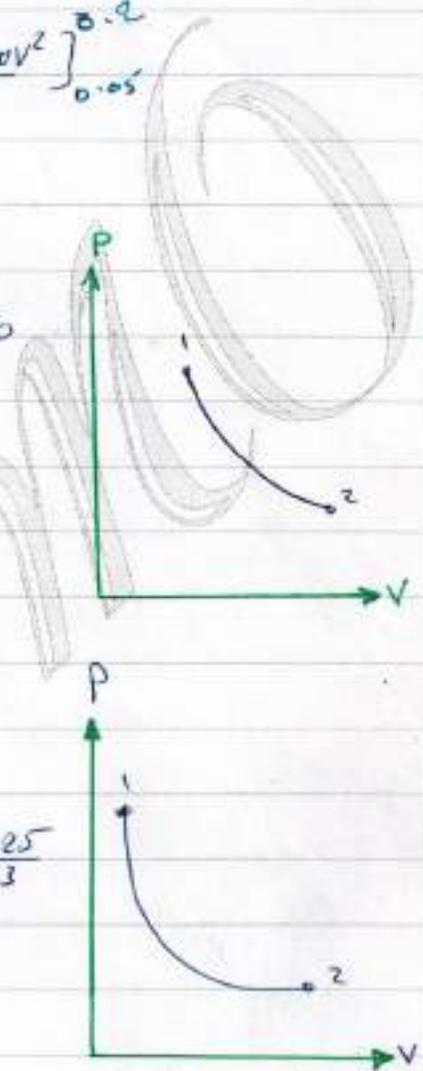
e.  $P = \frac{A}{V^2} - \frac{B}{V} \Rightarrow 10 \times 10^2 = \frac{A}{0.05^2} - \frac{B}{0.05}, \quad 1 \times 10^2 = \frac{A}{0.1^2} - \frac{B}{0.1}$

$$\therefore A = 4 \quad B = 30$$

$$\therefore P = \frac{4}{V^2} - \frac{30}{V}$$

$$w = \int p \, dV = \int_{0.1}^{0.2} \left( \frac{4}{V^2} - \frac{30}{V} \right) dV = \left[ -\frac{4}{V} - 30 \ln V \right]_{0.1}^{0.2}$$

$$\therefore w = 19.2 \text{ kJ}$$





**Ex:** A fluid is heated reversibly at a constant pressure of 1.05 bar until it has a specific volume of  $0.1 \text{ m}^3/\text{kg}$ . It is then compressed reversibly according to a law  $pV=c$  to a pressure 4.2 bar, then allowed to expand reversibly according to a law  $pV^{1.3}=c$  and finally heated at constant volume back to initial condition. The work done in the constant pressure process is 515 N.m and the mass of fluid present is 0.2 kg. Calculate the net work done on or by the fluid in the cycle and sketch the cycle on the  $pV$  diagram.

**Sol:**

$P_1 = 1.05 \text{ bar}$	$v_1 = ?$
$P_2 = P_1 = 1.05 \text{ bar}$	$v_2 = 0.1 \text{ m}^3/\text{kg}$
$P_3 = 4.2 \text{ bar}$	$v_3 = ?$
$P_4 = ?$	$v_4 = v_1$

- Process 1  $\rightarrow$  2,  $w_{1-2} = 515 \text{ N.m}$

$$w = \int P \cdot dv = p_1 \int dv = p_1(v_2 - v_1)$$

$$W = m \cdot w = m[p_1(v_2 - v_1)]$$

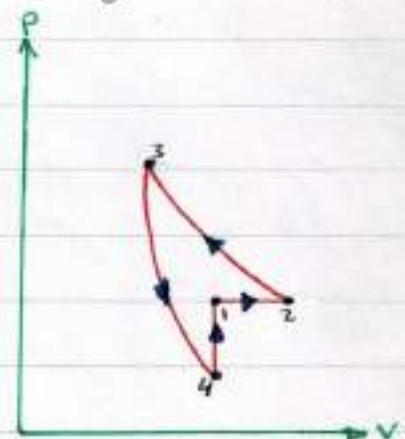
$$515 = 0.2 \times 1.05 \times 10^5 (0.1 - v_1)$$

$$v_1 = 0.075 \text{ m}^3/\text{kg}$$

- Process 2  $\rightarrow$  3,  $pV=c \Rightarrow p_2 v_2 = c$

$$1.05 \times 10^5 \times 0.1 = c \Rightarrow c = 10500$$

$$p = \frac{c}{V}$$





$$w = \int_2^3 P dv = C_2 \int_2^3 \frac{dv}{v} = 10500 [\ln v_3 - \ln v_2]$$

$$\therefore P_2 v_2 = P_3 v_3 \Rightarrow v_3 = \frac{P_2}{P_3} \cdot v_2 = \frac{1.05}{4.2} \times 0.1 = 0.025 \frac{\text{m}^3}{\text{kg}}$$

$$\therefore w = 10500 [\ln 0.025 - \ln 0.1] = -14556 \frac{\text{N}\cdot\text{m}}{\text{kg}}$$

$$W_{2-3} = m \cdot w = 0.2 \times -14556 = -2911.2 \text{ N}\cdot\text{m} = -2911.2 \text{ Joule}$$

- Process 3-4,  $P v^{1.3} = C$

$$v_4 = v_1 = 0.075 \frac{\text{m}^3}{\text{kg}}$$

$$P_3 v_3^{1.3} = P_4 v_4^{1.3} = C$$

$$\therefore P = \frac{C}{v^{1.3}}$$

$$w = \int_3^4 P dv = \int_3^4 C \frac{dv}{v^{1.3}} = P_3 v_3^{1.3} \int_3^4 \frac{dv}{v^{1.3}}$$

$$w = P_3 v_3^{1.3} \left[ -\frac{1}{0.3 v^{0.3}} \right]_3^4 = 4.2 \times 10^5 (0.025)^{1.3} \left[ -\frac{1}{0.3 (0.075)^{0.3}} + \frac{1}{0.3 (0.025)^{0.3}} \right]$$

$$= 9827.4 \text{ J/kg}$$

$$W_{3-4} = m \cdot w_{3-4} = 0.2 \times 9827.4 = 1965.5 \text{ J}$$

$$w_{4-1} = \int_4^1 P dv \quad \text{since } v=C \Rightarrow dv=0 \quad \therefore w=0$$

$$W_{\text{net}} = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

$$= 515 + (-2911.2) + 1965.5 + 0$$

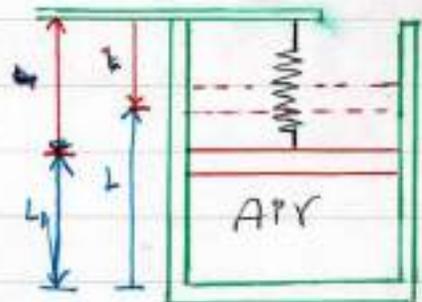
$$= -430.7 \text{ Joule}$$

$$= -0.4307 \text{ kg} \quad (\text{work done on the system})$$



Ex: consider the system shown in figure. the initial volume inside the cylinder is  $(0.1 \text{ m}^3)$ . At this state the pressure inside is  $(100 \text{ kPa})$ , which just balance the atmospheric 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  $(300 \text{ kPa})$ , 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, what percentage of work is done against the spring.

Sol:  $P_1 = 100 \text{ kPa}$      $V_1 = 0.1 \text{ m}^3$   
 $P_2 = 300 \text{ kPa}$      $V_2 = 0.2$



force  $\propto \Delta L$      $\Delta L = L_2 - L_1 = L - L_1$

$F_s \propto (L - L_1) \Rightarrow \frac{F_s}{A} \propto \frac{L - L_1}{A} \cdot \frac{A}{A}$

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

$P_s = \frac{c}{A^2} (V - V_1) = a(V - V_1)$  , at  $p = 300$  ,  $V = 0.2$

$P_t = P_0 + P_s = 100 + a(V - V_1)$

$300 = 100 + a(0.2 - 0.1) \Rightarrow a = 2000$



$$\therefore P_t = 100 + 2000(V - 0.1) = 100 - 200 + 2000V = 2000V - 100$$

$$W = \int_1^2 p \, dV = \int_1^2 (2000V - 100) \, dV$$

$$W_{1-2} = \left[ \frac{2000V^2}{2} - 100V \right]_1^2$$

$$W_{1-2} = \left( \frac{2000(0.2)^2}{2} - 100(0.2) \right) - \left( \frac{2000(0.1)^2}{2} - 100(0.1) \right) \\ = 20 \text{ kJ}$$

If there is no Spring the piston will rise at constant pressure

$$W = \int_1^2 p \cdot dV = p \int_1^2 dV$$

$$= p(V_2 - V_1)$$

$$= 100(0.2 - 0.1)$$

$$= 10 \text{ kJ}$$

$$\% = \frac{10}{20} = 50\%$$

hand  
BEB



**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 the 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 m<sup>3</sup>/kg.

**Sol:**

from Steady Flow Energy Equation

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

$$z_1 \approx z_2$$

$$\text{power} = 14000 \text{ kW}$$

$$p = \dot{m} \cdot w \Rightarrow w = 14000/17 = 823.53 \text{ kJ/kg}$$

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

$$\therefore q = (h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) \times 10^{-3} + w$$

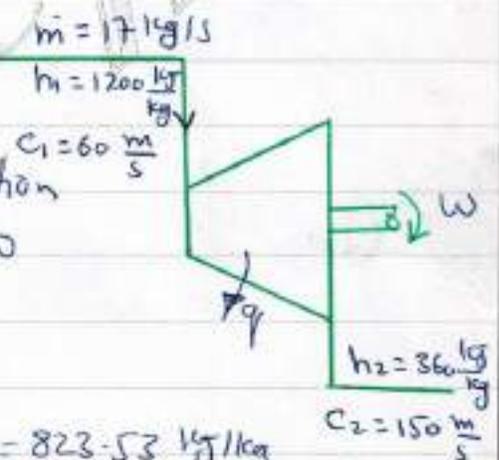
$$= (360 - 1200) + \frac{1}{2}(150^2 - 60^2) \times 10^{-3} + 823.53$$

$$= -7.05 \text{ kJ/kg}$$

$$= 7.05 \text{ rejected heat}$$

$$\dot{Q} = \dot{m} \cdot q = 17 \times (-7.05) = -119.85 \text{ kW}$$

$$\dot{m} = \frac{C_1 A_1}{v_1} \Rightarrow A_1 = \frac{\dot{m} \cdot v_1}{C_1} = \frac{17 \times 0.5}{60} = 0.142 \text{ m}^2$$





**Ex:10** Air flows at a rate of 0.4 kg/s through an air compressor entering at 6 m/s, 1 bar and  $0.85 \text{ m}^3/\text{kg}$  and leaving at 4.5 m/s, 6.9 bar and  $0.16 \text{ m}^3/\text{kg}$ . The internal energy of the air leaving is greater than that of entering air by 88 kJ/kg, cooling water in the jacket surrounding the cylinder absorbs heat from the air at the rate of 59 kJ/s. Find the power required to drive the compressor and the inlet and outlet pipe cross-sectional area.

**Sol:10** from Steady flow EE

$$gz_1 + P_1 v_1 + u_1 + \frac{1}{2} C_1^2 + q = gz_2 + P_2 v_2 + u_2 + \frac{1}{2} C_2^2 + w$$

$$Q = \dot{m} \cdot q \Rightarrow q = 59 / 0.4 = 147.5 \text{ kJ/kg}$$

$$P_1 v_1 + u_1 + \frac{1}{2} C_1^2 + q = P_2 v_2 + u_2 + \frac{1}{2} C_2^2 + w \quad (u_2 - u_1 = 88 \text{ kJ/kg})$$

$$w = (P_1 v_1 - P_2 v_2) + (u_1 - u_2) + \frac{1}{2} (C_1^2 - C_2^2) \times 10^{-3} + q \quad (z_1 \approx z_2)$$

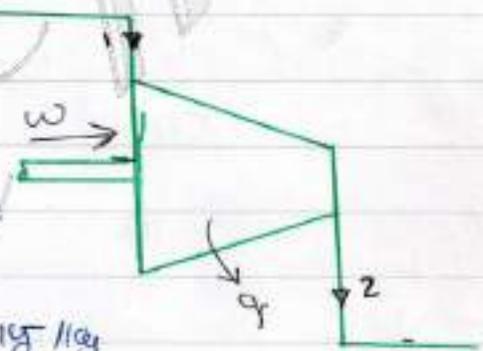
$$w = (1 \times 10^5 \times 0.85 - 6.9 \times 10^5 \times 0.16) + (-88) + \frac{1}{2} (6^2 - 4.5^2) \times 10^{-3} + (-147.5)$$

$$= -260.9 \text{ kJ/kg}$$

$$W = \dot{m} \cdot w = 0.4 \times (-260.9) = -104.35 \text{ kW}$$

$$A_1 = \frac{\dot{m} \cdot v_1}{C_1} = 0.057 \text{ m}^2$$

$$A_2 = \frac{\dot{m} \cdot v_2}{C_2} = 0.0148 \text{ m}^2$$





## ( Sheet No. 1 )

Q1:0

1 kg of fluid is compressed reversibly according to a  $pV = 0.25$ , where  $p$ , in bar and  $v$  in  $m^3/kg$ . The final volume is one fourth the initial volume. Calculate the work done on the fluid and sketch the process on  $p-v$  diagram.

Ans. [ 34.660 N.m ]

Q2:0

$0.05 m^3$  of gas at 6.9 bar expands reversibly in a cylinder behind a piston according to a 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  $p-v$  diagram.

Ans. [ 15.300 N.m ]

Q3:0

One kilogramme of fluid expand reversibly according to a linear law from 4.2 bar to 1.4 bar. The initial and final volume are  $0.004 m^3$  and  $0.02 m^3$  respectively. The fluid is then cooled reversibly at constant pressure, and finally compressed reversibly according to a law  $pV = c$  back to initial condition of 4.2 bar and  $0.004 m^3$ . Calculate the work done for each process, the net work done and sketch the cycle on  $p-v$  diagram.

Ans. [ 4480 J, -1120 J, -1845 J, 1515 J ]



Q4:  $0.09 \text{ m}^3$  of fluid at  $0.7 \text{ bar}$  is compressed reversibly to a pressure of  $3.5 \text{ bar}$  according to a law of  $p v^n = c$ . The fluid is then heated reversibly at constant volume until the pressure is  $4 \text{ bar}$ , the specific volume is  $0.5 \text{ m}^3/\text{kg}$ . A reversible expansion according to a law  $p v^2 = c$  restores the fluid to its initial state. Calculate the mass of the fluid present, the value of  $(n)$  and the net work done on or by the system. Sketch the cycle on  $p-v$  diagram.

Ans. [  $0.0753 \text{ kg}$ ,  $1.85$ ,  $676 \text{ N}\cdot\text{m}$  ]

Q5:

Air at  $200 \text{ kPa}$ ,  $30^\circ \text{C}$  is contained in a cylinder/piston with initial volume of  $0.1 \text{ m}^3$ . The inside pressure balances ambient pressure of  $100 \text{ kPa}$  plus an external imposed force that proportional to  $v^{0.5}$ . Now heat is transfer to the system to final pressure of  $225 \text{ kPa}$ . Find the work done for this process.

Ans. [  $8.65 \text{ kJ}$  ]

Q6: In an air compressor, the compression is takes place at constant internal energy, and  $50 \text{ kJ}$  of heat is rejected to the cooling water for every one kilogram of air. Find the work required for the compression.

Ans. [  $50 \text{ kJ/kg}$  ]



Q7: In a compression stroke of gas engine the work done on the gas by the piston is  $70 \text{ kJ/kg}$  and heat rejected to the cooling water is  $42 \text{ kJ/kg}$ . Find the change of internal energy. Stating whether it is gain or lost.

Ans.  $[28 \frac{\text{kJ}}{\text{kg}}]$

Q8: A mass of gas with an internal energy of  $1500 \text{ kJ}$  is contained in a cylinder which has perfect thermal insulated. The gas is allowed to expand behind a piston until its internal energy is  $1400 \text{ kJ}$ . Calculate the work done by the gas. If the expansion follows a law  $pV^2 = c$  and the internal energy is changed, and initial pressure and volume are  $28 \text{ bar}$  and  $0.06 \text{ m}^3$  respectively. Calculate the final pressure and volume.

Ans.  $[100 \text{ kJ}, 4.59 \text{ bar}, 0.418 \text{ m}^3]$

Q9: A Steam turbine receives a steam flow at  $1.35 \frac{\text{kg}}{\text{s}}$  and delivers  $5000 \text{ kW}$ . The heat loss from the casing is negligible. Find a. the change of enthalpy across this turbine when the velocities at entrance and exit and the difference in elevation at entrance and exit are negligible. b. the change of enthalpy across the turbine when the velocity at entrance and exit are  $60 \frac{\text{m}}{\text{s}}$  and  $360 \frac{\text{m}}{\text{s}}$ , and the inlet pipe is  $3 \text{ m}$  above the exhaust pipe.

Ans.  $[-3704 \text{ kJ/kg}, -3766 \text{ kJ/kg}]$



Q10: A steady flow of steam enters a condenser with an enthalpy of  $2300 \text{ kJ/kg}$  and velocity of  $350 \text{ m/s}$ . The condensate leaves the condenser with an enthalpy of  $160 \text{ kJ/kg}$  and velocity of  $70 \text{ m/s}$ . Find the heat transfer to the cooling water per  $\text{kg}$  of steam.

Ans.  $[-2199 \text{ kJ/kg}]$

Q11: A turbine receives steam at  $13.8 \text{ bar}$ ,  $0.143 \text{ m}^3/\text{kg}$ , internal energy  $2590 \text{ kJ/kg}$ , and  $30 \text{ m/s}$ . At leaving the condenser is  $0.35 \text{ bar}$ ,  $4.37 \text{ m}^3/\text{kg}$ , internal energy  $2360 \text{ kJ/kg}$  and  $90 \text{ m/s}$ . Heat is lost to surrounding at  $0.25 \text{ kJ/k}$ . If the rate of steam flow is  $0.38 \text{ kg/s}$ , what is the power developed by the turbine.

Ans.  $[102.8 \text{ kW}]$

Q12: A nozzle is a device for increasing the velocity of fluid. At inlet to a nozzle the enthalpy is  $3026 \text{ kJ/kg}$  and the velocity is  $60 \text{ m/s}$ . At exit from the nozzle the enthalpy is  $2790 \text{ kJ/kg}$ . The nozzle is horizontal and there is negligible heat loss from the turbine.

a. Find the velocity at the nozzle exit.  $[688 \text{ m/s}]$

b. If the inlet area is  $0.1 \text{ m}^2$  and the specific volume at the inlet is  $0.19 \text{ m}^3/\text{kg}$ , find the mass flow rate.  $[0.36 \text{ kg/s}]$

c. If  $v = 0.5 \text{ m}^3/\text{kg}$  find the exit area of the nozzle.  $[0.0229 \text{ m}^2]$



Q13: In a non-flow process there is a heat loss of 105518 and an internal energy increase of 210 kJ. How much work is done and is the process expansion or compression.

Ans. [-1265 kJ, Comp.]

Q14: Air and fuel enter furnace used for home heating. The air has an enthalpy of 320 kJ/kg and the fuel an enthalpy of 43027 kJ/kg. The gases leaving the furnace has an enthalpy of 616 kJ/kg. There are 17  $\frac{\text{kg}_a}{\text{kg}_f}$  water circulate through the wall furnace receiving heat. The house required 17.02 kW of heat, what is the fuel consumption per day.

Ans. [41 kg/day]

1500