BASIC MECHANICAL ENGINEERING (3110006)

BE 1ST YEAR

CHAPTER-1: Introduction

Prime mover

A prime mover is defined as a device which converts energy from natural sources into mechanical energy or useful work (shaft power). Examples of prime movers are: Wind turbine, steam turbine, water turbine, I.C. Engine, etc.

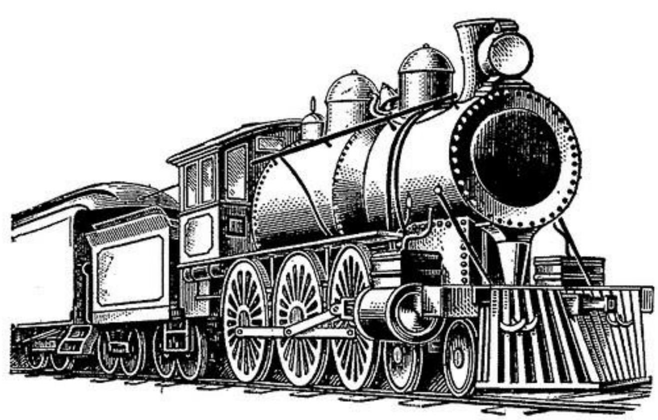
Sources of energy

Prime movers use various natural sources of energy like fuel, water energy, atom, biomass, wind etc.

1. **Fuel:** When fuel is burnt, heat energy is generated. Amount of heat generated by burning of fuel depends upon calorific value of that fuel. By using heat engine, the heat energy is converted into mechanical energy (shaft power). Various types of fuels are coal, petrol, diesel, gas etc.
2. **Water Energy:** Water stored at high elevation contains potential energy. When water starts flowing, potential energy gets converted to kinetic energy. Hydraulic turbine is a prime mover which converts kinetic energy of flowing water into mechanical energy. For example water stored in dam contains potential energy.
3. **Atoms (Nuclear Energy):** Heat energy produced by the fission (nucleus is divided into two or more fragments) or fusion (two lighter atomic nuclei fuse to form a heavier nucleus) of atoms may be used to produce heat. This heat is used to produce shaft power by heat engines.
4. **Non-conventional Energy Sources:** These energy resources replace themselves naturally in a relatively short time and therefore will always be available. Examples of these resources are solar energy, wind energy, tidal energy, bio energy, solid wastes etc. Almost all non-conventional energy resources offer pollution free environment.

Types of prime movers

The prime mover can be classified according to the sources of energy utilized. The classification of prime movers is shown in fig. 1.2.



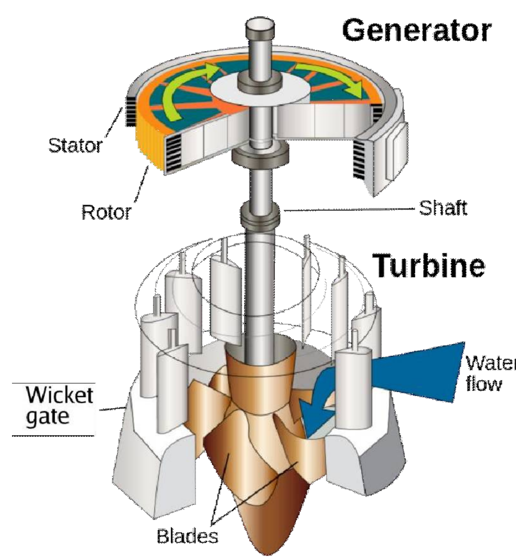


Fig 1.1 Examples of Prime mover (Steam engine and water turbine)

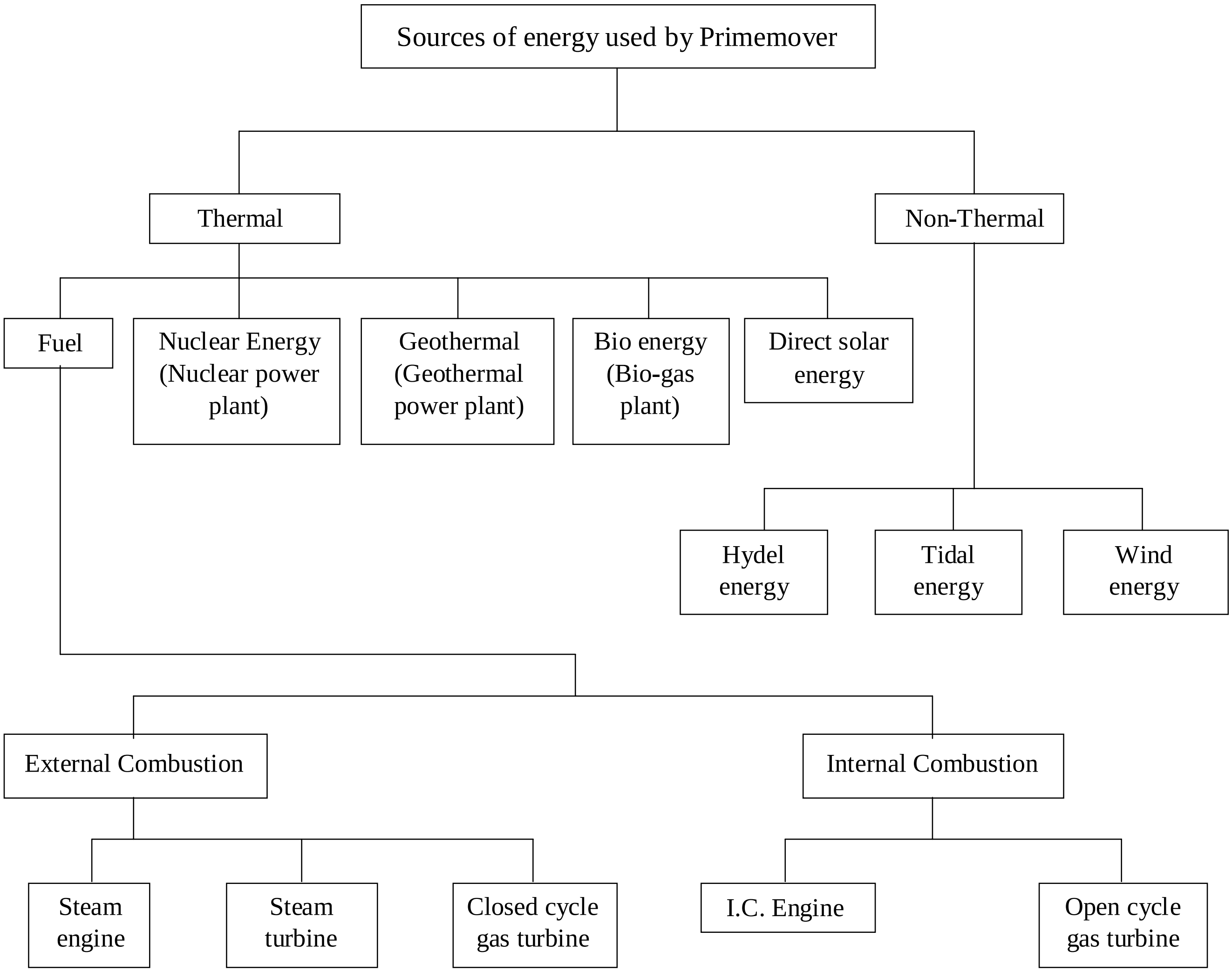


Fig. 1.2 Classification of prime movers

Basic Definitions

Mass

It is quantity of matter contained in a body. It does not depend upon gravitational force. The fundamental unit of mass is the Kilogram (kg).

Weight

Weight is the force exerted by gravity. Weight of body is dependent upon gravitational force, so it is not constant.

Weight = Mass x Gravitational acceleration

$$W = m \times g$$

Force

It is push or pull acting on a body which changes or tends to change the state of rest or uniform motion of the body.

As per Newton's second law of motion

$$Force \propto acceleration$$

$$F = m \times a$$

In SI unit (International system), unit of mass is kg and unit of acceleration is m/s^2 and unit of the force is Newton (N).

When m = 1 kg, and a = 1 m/s^2 then F = 1 N.

1 N: When unit mass is given unit acceleration then the force produced is 1 N.

Pressure

It is the force exerted by fluid (liquid or gas) on unit area. It is a property of fluid.

$$Pressure = \frac{Force}{Area} = \frac{N}{m^2}$$

The unit of pressure is known as Pascal (Pa) or N/m^2

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

Other commonly used units of pressure are:

1 kPa (Kilo Pascal) = 10^3 Pa

1 Mpa (Mega Pascal) = 10^6 Pa

1 bar = 10^5 Pa

Measurement of pressure:

Pressure is measured by Barometer, Pressure gauges and manometers.

Atmospheric pressure:

It is the pressure exerted by atmosphere. The atmospheric pressure varies from place to place. At sea level the pressure is,

1 standard atmosphere (atm) = 101325 Pa = 1.01325 bar

Barometer is used to measure atmospheric pressure.

Standard atmospheric pressure:
It is a pressure of atmospheric air at mean sea level. It is defined as “The pressure produced by a mercury column of 760 mm high having a density of 13595.09 kg/m^3 and acceleration due to gravity being 9.80665 m/s^2.”

Now, $pressure = \rho \times g \times h$

$= 13595.09 \times 9.80665 \times 760 \times 10^{-3}$

$= 1.01325 \times 10^{5}$ N/m^2 = 1.01325 bar

Gauge pressure:

The pressure relative to the atmosphere is called gauge pressure. This pressure is measured by pressure gauge.

Absolute pressure

It is the pressure measured with reference to absolute zero pressure. It is the pressure related to perfect vacuum.

Mathematically, **Absolute pressure = Atmospheric pressure + Gauge pressure**

Vacuum:

The pressure below atmospheric pressure is called vacuum. A perfect vacuum is obtained when absolute pressure is zero; at this instant molecular momentum is zero. The relation between different pressures is given in Fig. 2.

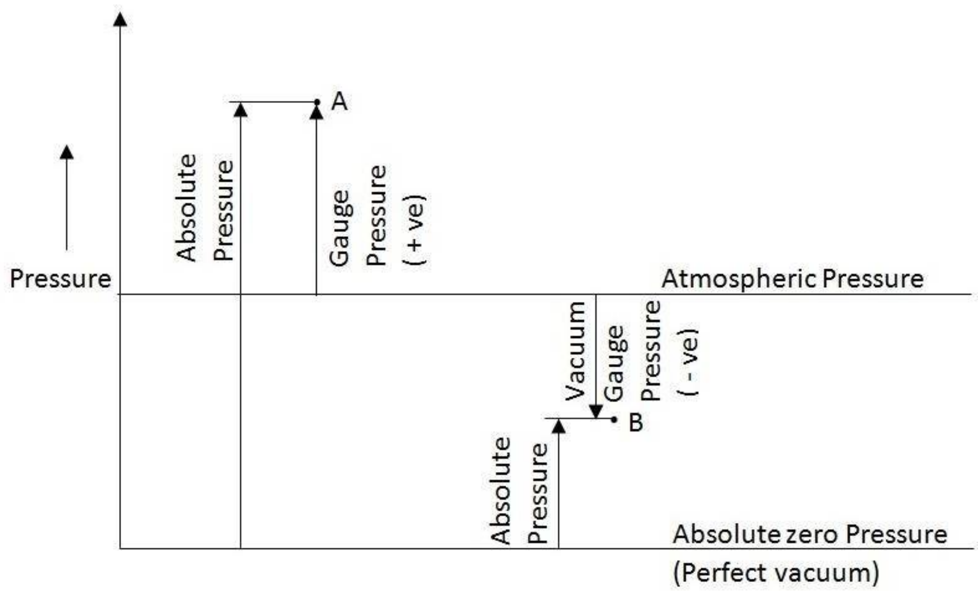


Fig. 1.3 Relation between different pressures

Work

Work is said to be done when a force moves the object through a distance in direction of force.

Hence, Work = Force x Distance moved into direction of force.

$$W = F \times d$$
$$W = \frac{F}{A} \times (A \times d)$$
$$W = P \times V$$

Unit of work is N·m or Joule (J).

Power

Power is defined as the rate of doing work OR the power is work done per unit time.

Mathematically, $Power = \frac{Workdone}{time}$ and unit of power is Joule/second.

In SI unit Joule/second is called Watt (W)

Watt is very small unit, so another larger units are megawatt (MW), Kilowatt (kW).

Energy

Energy means capacity for doing work.

The unit of energy is the unit of work i.e. Joule. In our daily life unit of energy use is Kilowatt hour (kWh).

Forms of energy:-

The different forms of energy are;

(1) Mechanical energy (2) Thermal or heat energy

(3) Chemical energy (4) Electrical energy-

(5) Nuclear energy

"Energy can neither be created nor be destroyed but the total amount of energy remains constant. It is possible to convert one form of energy into another form of energy." This is called the law of conservation of energy.

Quality of Energy

High grade energy: Energy that can be completely converted (neglecting loss) into the work.

Examples: Mechanical work, Electrical energy, Water power, Wind and tidal power, Kinetic energy of jet.

Low Grade energy: Only a certain portion of energy that can be converted into mechanical work (shaft power), that energy is called low grade energy.

Examples: Thermal or heat energy, Heat derived from combustion of fuels, Heat of nuclear fission.

Types of energy:

Energy may be classified as

(1) Stored energy

(2) Energy in transition

(1) Stored energy:

The stored energy of a substance may be in the form of mechanical energy, internal energy, nuclear energy etc.

(2) Energy in transition:

Energy in transition is the energy transferred as a result of potential difference.

This energy may be in the forms of heat energy, work energy, electrical energy.

Types of Mechanical Energy:

There are two types of mechanical energy

(1) Potential energy (2) Kinetic energy

1. **Potential energy:** The energy which a body possesses by virtue of its elevation or position is known as its potential energy.

   Example: Water stored at higher level in a dam

   Potential energy, $P.E. = m \times g \times h$

   Where

   m = mass of body in kg,

   g = gravitational acceleration = 9.81 m/s^2

   h = height in meter,

2. **Kinetic Energy:** The energy which a body possesses by virtue of its motion is known as its kinetic energy.

   Example: Jet of water coming out from nozzle.

   Kinetic Energy, $K.E = \frac{1}{2} mv^2$

   Where m = mass of body in kg, v = velocity of body in m/s.

Temperature

One is well familiar with the qualitative statement of the state of a system such as cold, hot, too cold, too hot etc. based on the day to day experience. The degree of hotness or coldness is relative to the state of observer. The temperature of a body is proportional to the stored molecular energy i.e. the average molecular kinetic energy of the molecules in a system.

Unit of temperature

In the International system (SI) of unit, the unit of thermodynamic temperature is Kelvin. It is denoted by the symbol K. However, for practical purposes the Celsius scale is used for measuring temperature. It is denoted by degree Celsius, °C.

Absolute zero temperature:

It is the temperature at which the volume occupied by the gas becomes zero. This is the lowest temperature that can be measured by a gas thermometer.

Temperature Scale:

A look at the history shows that for quantitative estimation of temperature a German instrument maker Mr. Gabriel Daniel Fahrenheit (1686-1736) came up with idea of instrument like thermometer and developed mercury in glass thermometer.

In the year 1742, a Swedish astronomer Mr. Anders Celsius described a scale for temperature measurement. This scale Later on became very popular and is known as Centigrade Scale or Celsius scale. Some standard reference points used for international practical Temperature Scale are given in Table 1.

Table 1.1 Comparison of Scales

Sr No.	State	Temperature °C	Temperature K
1	Ice point	0	273.15
2	Steam Point	100	373.15
3	Triple point of water	0.010	273.16
4	Absolute zero	-273.15	0

Heat

When two bodies at different temperatures are brought into contact there are observable changes in some of their properties and changes continue till the two don't attain the same temperature if contact is maintained. Thus, there is some kind of energy interaction between two bodies which causes change in temperatures. This form of energy interaction is called heat.

Heat may be defined as the energy interaction at the system boundary which occurs due to temperature difference only.

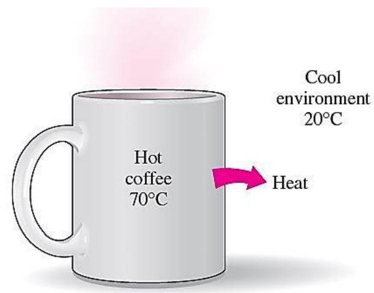


Fig. 1.4 Heat flows in the direction of decreasing temperature

Interchange of heat

Let us consider two bodies, hot body and cold body. When hot body comes in contact with cold body, the heat will flow from hot body to cold body. This interchange of heat is due to temperature difference. See fig. 1.5.

$T_1 > T_2$

Hot Body (T_1)	Cold Body (T_2)

Heat flow →

Fig. 1.5 Interchange of heat

There will be no heat flow if both the bodies in contact have equal temperature.

Units of heat

Heat is a form of energy. In SI system, unit of heat is taken as joule. Kilojoules (kJ) and Mega joule (MJ) are recommended larger units of heat.

Calorie (cal.) is also unit of heat. Generally Kilocalorie (kcal) is quantity of heat required to raise temperature of unit mass of water through one degree Celsius or Kelvin.

1 kcal = 4186.8 joules = 4.1868 kilo joules

Specific heat

It is defines as the quantity of heat required to raise the temperature of unit mass of the substance by one degree.

The unit of specific heat is kJ/kg K or J/kg K depending on the unit of Q.

From the definition of specific heat, the heat transfer Q is written as

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

$$\therefore C = \frac{Q}{m \times \Delta T}$$

$$= \frac{Q(kJ)}{m\,(kg)\times \Delta T\,(K)}$$

Heat capacity: The product of mass and specific heat is called the heat capacity of the substance.

Specific heat is function of temperature; hence it is not constant but varies with temperature. Generally it is assumed that it is constant.

Specific heats in thermodynamics

The solids and liquids have only one value of specific heat but a gas is considered to have two distinct values of specific heat capacity.

(i) A value when the gas is heated at constant volume, C_V

(ii) A value when the gas is heated at constant pressure C_P

The specific heat at constant volume C_V: It is defined as the heat required to increase the temperature of the unit mass of a gas by one degree as the volume is maintained constant.

The specific heat at constant volume C_P: It is defined as the heat required to increase the temperature of the unit mass of a gas by one degree as the pressure is maintained constant.

Change of state

The various states of substance (Phases) are Solid, Liquid and Vapour/Gas. When heat is supplied to a substance at the solid phase, its temperature rises until it starts converting into liquid.

Table 1.2 Phase change terminology

Sr.	Phase change	Name	Process
1	Solid to liquid	Fusion	Melting
2	Solid to vapour	Sublimation	Defrosting
3	Liquid to vapour	Evaporation	Evaporating
4	Liquid to solid	Fusion	Freezing
5	Vapour to solid	Sublimation	Frosting
6	Vapour to liquid	Condensation	Condensing

Melting point: It is the temperature at which the solid is converted into liquid when heat is supplied.

Boiling point: It is the temperature at which the liquid is converted into vapour when heat is supplied.

Critical point: It is the temperature and pressure above which only one phase is existing i.e. vapour.

Triple point: Triple point of a substance refers to the state at which substance can coexist in solid, liquid and gaseous phase in equilibrium. For water triple point is 0.010 °C i.e. at this temperature ice, water and steam can coexist in equilibrium.

Thermodynamic systems

A system is defined as a quantity of matter or a region in space chosen for study. Examples: quantity of steam, turbine etc.

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

The real or imaginary surface that separates the system from its surroundings is called the **boundary.** These terms are illustrated in fig. 1.6.

The boundary of a system can be *fixed* or *movable. Note that the boundary is the contact surface shared by both the system and the surroundings.*

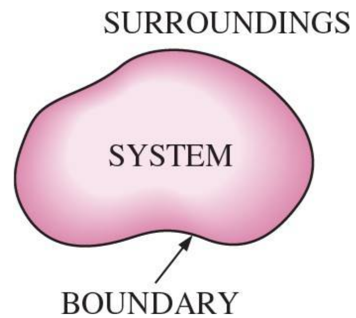


Fig. 1.6 System, surrounding and boundary

The system is identified by a boundary around the system. A system and its surroundings together are called the universe.

Universe = system + surroundings

Types of system

There are three types of system

(1) Open system, (2) Closed system and (3) Isolated system

1. Open system

In an open system mass and energy (in form of heat and work) both can transfer across the boundary (fig. 1.7).

Most of the engineering devices are open system. Examples: Boiler, turbine, compressor, pump, I.C. engine etc.

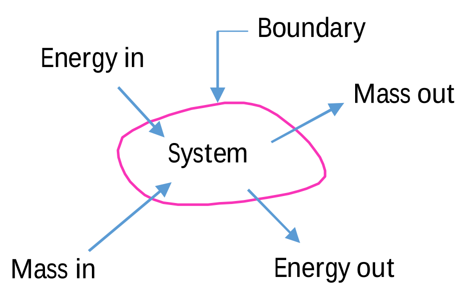


Fig. 1.7 An open system

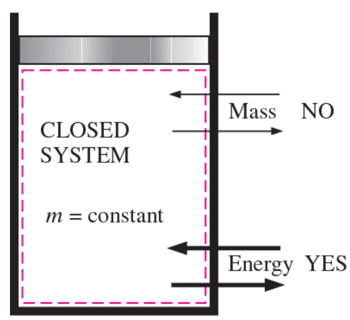


Fig. 1.8 A closed system

2. Closed system

A closed system exchange energy in the form of heat and work with its surroundings but there is no mass transfer across the system boundary (fig. 1.8).

The mass within the system remains constant though its volume can change against a flexible boundary. Example: cylinder bounded by a piston with certain quantity of fluid, pressure cooker etc.

3. Isolated system

There is no interaction between system and surroundings.

It is of fixed mass and energy, and hence there is no mass and energy transfer across the system boundary (fig. 1.9).

Example: The universe and perfectly insulated closed vessel (Thermo flask)

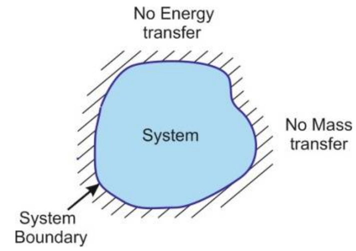


Fig. 1.9 An isolated system

Control Volume

For thermodynamic analysis of an open system, such as an air compressor, turbine, etc. attention is focused on a certain volume in space surrounding the system, known as control volume.

The control volume bounded by the surface is called **"Control Surface"**.

Both mass and energy can cross the control surface. It may be physical or imaginary. Example of control volume:

A diagram of an engine is shown in Fig. 1.10(*a*). The dashed line defines a control volume that surrounds the engine. Observe that air, fuel, and exhaust gases cross the boundary. A schematic such as in Fig. 1.10(*b)* often serves for engineering analysis.

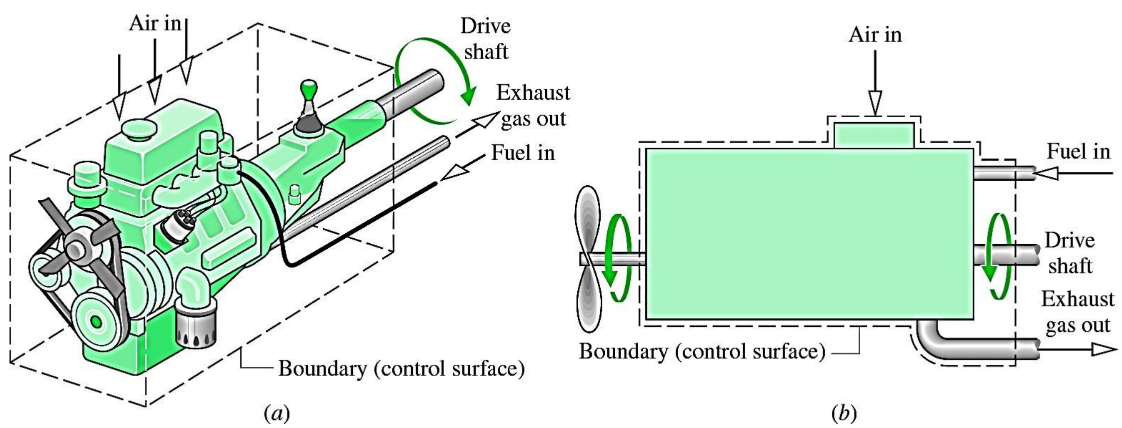


Fig. 1.10 Example of a control volume (open system) - An automobile engine

Sign convention for heat and work

Work

If the work is done by the system on surrounding, e.g. when a fluid expands pushing a piston outwards, the work is said to be positive.

Work output of the system = + W

If the work is done on the system by surrounding e.g. when a force is applied to a piston to compress a fluid, the work is said to be negative.

Work output of the system = - W

Heat

In general, the heat transferred to the system is considered as ***positive heat (+Q)*** while the heat transferred from the system is considered as ***negative heat (-Q)***.

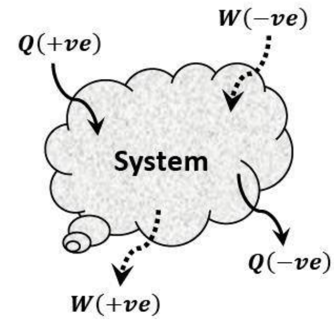


Fig. 1.11 Sign convention for heat and work

Comparison between heat and work

Similarities

1. Both are energy interactions.
2. Both are transient phenomena.
3. Both are boundary phenomena.
4. Both represents energy crossing the boundary of the system.
5. They are not the property of the system.
6. Both are path functions.

Dissimilarities

1. Heat transfer is the energy interaction due to temperature difference only while work is not.
2. Heat is low grade energy while work is high grade energy.
3. Heat is thermal energy transfer while work is mechanical energy transfer across the system boundary.

Internal energy

In non-flow processes, fluid does not flow and has no kinetic energy. There is very small amount of change in potential energy because change in centre of gravity is negligible.

When heat is supplied to a body the amount of heat transferred to a body is not fully converted to work. When heat (Q) is supplied to a body, some amount of heat is converted into external work (W) due to expansion of fluid volume and remaining amount of heat causes either to increase its temperature or to change its state.

Internal Energy is one type of energy which is neither heat nor work; hence it is stored form of energy. It is denoted by U. Mathematically,

$$Q = W + U$$

where Q is amount of heat, W is work and U is internal energy.

The internal energy per unit mass is called specific internal energy. Below equation is referred as non-flow energy equation. In other words, for non-flow process

$$\begin{Bmatrix}\text{Heat transferred through} \\ \text{system boundary}\end{Bmatrix} = \begin{Bmatrix}\text{Work transferred through} \\ \text{system boundary}\end{Bmatrix} + \begin{Bmatrix}\text{Change in} \\ \text{Internal energy}\end{Bmatrix}$$

Enthalpy

Enthalpy is a thermodynamic property of fluid, denoted by H. *It can be defined as the summation of internal energy and flow energy. Mathematically,*

$$H = \underbrace{U}_{\text{Internal energy}} + \underbrace{PV}_{\text{Flow work}}$$

On unit mass basis, the specific enthalpy could be given as

$$h = u + pv$$

From expression of enthalpy it is clear that as we cannot have absolute value of internal energy, the absolute value of enthalpy cannot be obtained. Therefore only change in enthalpy of substance is considered.

Thermodynamic properties, Processes and Cycle

Thermodynamic property

"A thermodynamic property refers to the characteristics which can be used to describe the physical condition or state of a system."

Examples of thermodynamic properties are: Temperature, Pressure, Volume, Energy, Mass, Velocity, etc.

Types of thermodynamic property:

1. Intensive Property

Intensive property is **In**dependent of the mass of the system. Its value remains same whether one considers the whole system or only a part of it.

Examples: Pressure, Temperature, Density, etc.

2. Extensive Property

Extensive property depends on mass of the system.

Examples: Mass, Volume, Total energy, Enthalpy etc.

3. Specific Property

Extensive properties per unit mass are called specific properties.

Example: Specific volume $\left(v = \frac{V}{m}\right)$ and specific enthalpy $\left(h = \frac{H}{m}\right)$

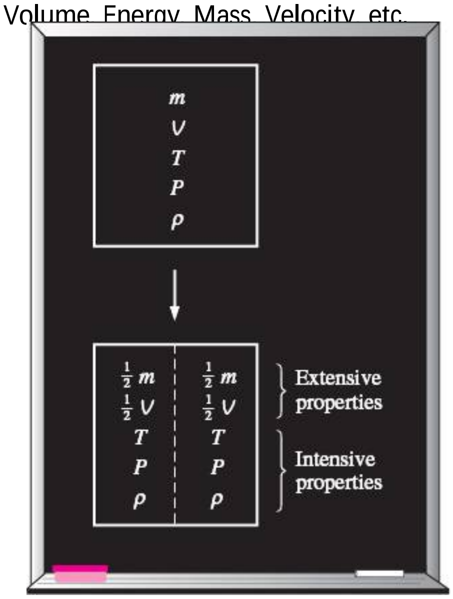


Fig. 1.12 Criterion to differentiate Intensive and extensive properties

State

State refers to the condition of a system as described by its properties. It gives complete description of the system. At a given state, all the properties of a system have fixed values.

If the value of even one property changes, the state will change to a different one (fig. 1.13)

Equilibrium

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

A system is in **thermal equilibrium** if the temperature is same throughout the entire system.

Mechanical equilibrium is related to pressure. If there is no change in pressure at any point in the system with time the system is in mechanical equilibrium.

Chemical equilibrium is that state when the chemical composition does not change with time and there is no chemical reaction.

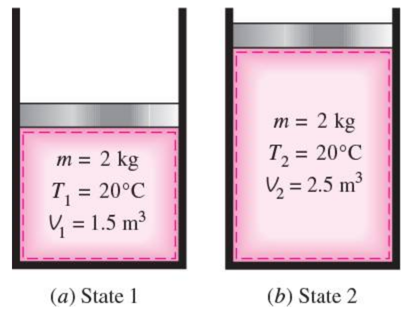


Figure 1.13 A system at two different states

A system will be in **thermodynamic equilibrium** only when it satisfies the conditions for all modes of equilibrium.

Process and path

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 (Figure 1.14).

To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the interactions with the surroundings.

There are infinite ways for a system to change from one state to another.

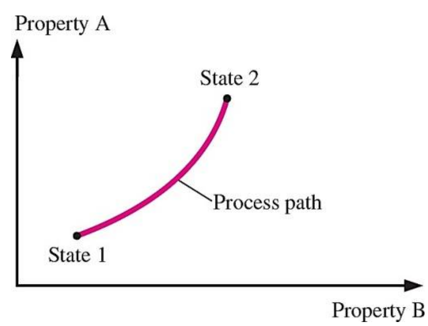


Fig. 1.14 A process between states 1 and 2 and the process path

Cycle

When a system in a given initial state goes through a number of different changes of state or processes and finally returns to its initial state, the system has undergone a **cycle.** Thus for a cycle the initial and final states -are identical.

Example: Steam that circulates through a steam power plant undergoes a cycle.

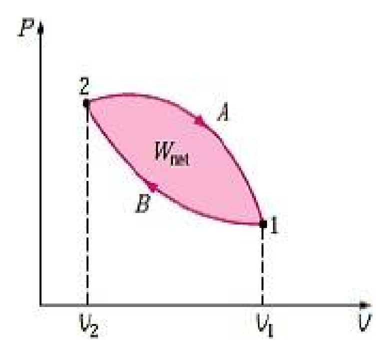


Fig. 1.15 Cyclic Process

Zeroth law of Thermodynamics

Zeroth law of thermodynamics states that *"the bodies A and B are in thermal equilibrium with a third body C separately then the two bodies A and B shall also be in thermal equilibrium with each other"*.

This is the principle of temperature measurement. Block diagram shown in fig. 1.16 shows the Zeroth law of thermodynamics.

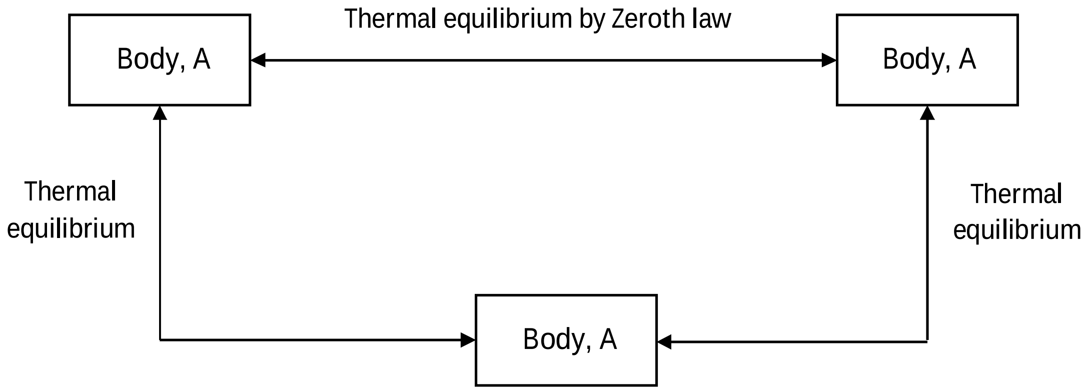


Fig. 1.16 Zeroth law of thermodynamics

First law of thermodynamics

The first law of thermodynamics is the law of conservation of energy and it states that "energy can neither be created nor destroyed, it can be converted from one form to another and total energy remains same".

Let us take water in a container and heat it from the bottom. What will happen? Container and the water inside will get heated up. This heating can be sensed by either touching it or by measuring its initial and final temperatures. What has caused it to happen so?

Answer for the above question lies in the energy interactions.

First law of thermodynamics provides for studying the relationships between the various forms of energy and energy interactions.

First law may be expressed as,

Change in total energy = net energy transferred as heat and work

$$\Delta E = Q - W$$

Where ΔE is summation of various energies like Internal energy (ΔU), Kinetic energy (ΔKE), Potential energy (ΔPE) etc.

$$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE....$$

In closed system, mass is fixed and there is no elevation difference and movement. Hence, ΔKE = 0 and $\Delta PE = 0$.

$$\Delta U = Q - W$$

For cyclic process ΔE = 0

Hence first law for a cyclic process is $Q - W = 0$.

That is, the net heat transfer and net work done during a cyclic process are equal.