

UNIT-1

INTRODUCTION TO THERMODYNAMICS, FUELS

INTRODUCTION TO THERMODYNAMICS

The branch of science that studies the laws of the conversion of heat energy into mechanical energy is called **Thermodynamics**.

THERMODYNAMIC SYSTEM

The region in the space that contains the matter whose behavior is to be investigated is called “Thermodynamic system”.

The envelope enclosing the system is called “Boundary” and everything outside the boundary is called surroundings.

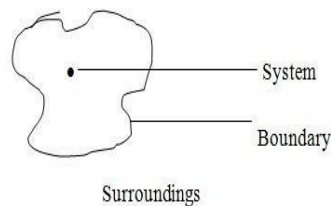


Fig. 1.1: Thermodynamic System

- a. **Working fluid:** The fluid on which the thermodynamics process is performed is called working fluid. Air, Gas, Vapour and Steam are few examples.
- b. **State of the System:** State is the condition of the system at any instant of time as described by its properties. The state of the system can be described by its properties like Temperature, Pressure, Volume, Density etc.,
- c. **Closed System:** Closed system contains fixed mass of matter. There is no transfer of mass across the system boundary. The heat and work crosses the boundary of the system. **Ex:** Internal combination of Engine

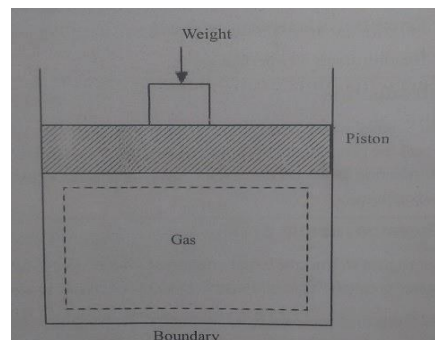


Fig. 1.2: Closed System

The figure shows a closed cylinder. The gas in the cylinder is considered as system. If heat is supplied to the cylinder from some external source, the temperature of the gas will increase and the piston will move. The heat and work energy crosses the boundary of the system and the mass remains with the system.

- d. Open System:** In open system the mass as well as the energy crosses the boundary of the system.
Ex: (1) Air compressor (2) The hot gases from the combustion chamber entering and leaving the turbine blades.
- e. Isolated System:** A system which cannot exchange energy with its environment is called isolated system. In this system neither the mass nor energy crosses the system boundary. **Ex:** Thermodynamics Universe.

THERMODYNAMIC PROPERTIES

The physical condition of any system can be described by certain characteristics like Volume, Temperature and Pressure. There are observable and measurable characteristics. These characteristics are called Thermodynamic properties.

These properties are divided into two classes

1. Intensive Properties
2. Extensive Properties

1. Intensive Properties: The intensive properties are those properties which do not depend on the mass of the system.

Ex: Pressure, Temperature, Specific volume, density etc.,

2. Extensive Properties: The properties which are dependent on the mass of the system are called extensive properties.

Ex: Mass, Volume, Internal Energy, Enthalpy etc.

DEFINITIONS OF SOME PROPERTIES

- 1. Pressure:** Pressure is defined as the force exerted on unit area. The unit of pressure in SI units is Pascal (N / m^2). In MKS system, the unit is Kg / cm^2 . Other units of pressure are bar, Kpa, Mpa.

$$1 \text{ bar} = 10^5 \text{ N/m}^2 = 100 \text{ KN} / \text{m}^2 = 100 \text{ Kpa} =$$

$$1 \text{ Mpa} = 10^6 \text{ Pascals} = 10^6 \text{ N} / \text{m}^2 = 10 \text{ bar}$$

- 2. Atmospheric Pressures:** The normal force exerted by the atmosphere on a unit surface area is called “Atmospheric Pressure”. This is measured by a mercury Barometer.

$$1 \text{ atm} = 760 \text{ mm of Hg} = 1.01325 \text{ bar}$$

a) Gauge Pressure: The pressure recorded by the instrument above the atmospheric pressure is gauge pressure.

b) Vacuum Pressure: The pressure recorded by the instrument below the atmospheric pressure is called Vacuum Pressure.

- 3. Absolute Pressure:** Any pressure measured above the absolute zero pressure is called absolute pressure.

$$\begin{aligned}\text{Absolute Pressure} &= \text{Atmospheric Pressure} + \text{Gauge Pressure} \\ &= \text{Atmospheric Pressure} - \text{Vacuum Pressure.}\end{aligned}$$

4 Volume: The space occupied by the system is called volume of the system. Its unit is m^3 and denoted by 'V'. It is also expressed in liters $10^3 \text{ Liters} = 1\text{m}^3$.

5 Specific Volume: The space occupied by a unit volume of substance is called specific volume. It is denoted by $v \text{ m}^3 / \text{kg}$. The specific volume is the reciprocal of density.

6 Temperature: Temperature is defined as the degree of hotness or level of integrity of heat in a body. It is measured by Thermometer in the following scales.

- 1) Centigrade Scale
- 2) Fahrenheit Scale

i) Centigrade Scale or Celsius Scale

The zero point on the scale represents the freezing point of water and the 100 point represents the Boiling point of water. Each division in this scale is 'One' degree centigrade and written as 0°C .

ii) Fahrenheit Scale:

In this scale, freezing point of water is marked as 32° and boiling point as 212. The space between these two points is divided into 180 units and each division represents degree Fahrenheit or 0°F .

The relationship between Celsius and Fahrenheit is given by $C = \frac{5}{9}(F - 32)$

iii) Absolute Temperature Scale: At lowest temperature, the gas occupies 'zero' volume. Therefore the lowest temperature at which volume of the gas is 'zero' is called Absolute temperature and it is equal to -273°C . Absolute temperature scale is called Kelvin Scale of Temperature. $K = ^\circ\text{C} + 273$.

7. Internal Energy: The internal energy is a function of temperature. It is denoted by 'U'. The internal energy of a substance is made up of two parts.

1. The internal Kinetic Energy (ΔK)
2. The internal potential energy (ΔP)

The total case of gases, the internal potential energy is small and hence neglected.

When a gas is heated from temperature T_1 to $T_2 \text{ K}$, then the change in internal energy is given as

$$\Delta U = U_2 - U_1 = M C_V (T_2 - T_1)$$

Where ΔU = change in internal

energy m = Mass of gas

T_n = Final temperature T_1 = Initial temperature

- 8 Enthalpy:** The sum of internal energy (U) and the product of pressure and volume is termed as enthalpy and it is denoted by 'H'.

$$H = U + PV$$

The change in enthalpy may be defined as the heat supplied at constant pressure.

$$H_2 - H_1 = m C_p(T_2 - T_1)$$

The units are Joules or Kilo Joules.

LAWS OF THERMODYNAMICS

The amount of useful work and power which can be developed by the engine, and the possible efficiency of the engine are governed by the laws of Thermodynamics.

ZEROth LAW OF THERMODYNAMICS

Zeroth Law of thermodynamics states that “if two bodies A & B are in Equilibrium with third body repeatedly, then the bodies A & B will also be in thermal Equilibrium with each other.

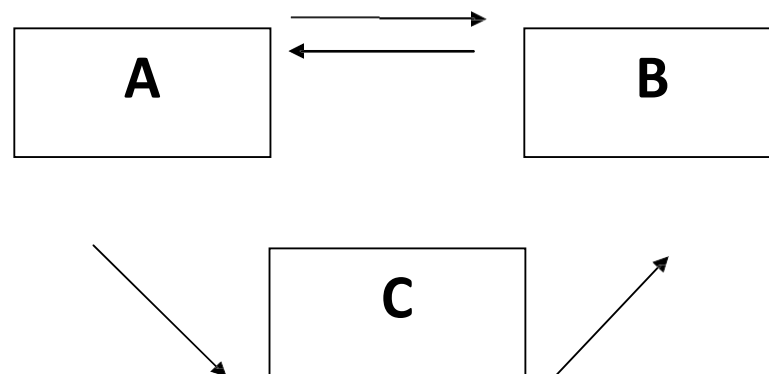


Fig. 1.3: Zeroth Law

FIRST LAW OF THERMODYNAMICS

The first law of Thermodynamics is a corollary of the general law of conservation of Energy. This law establishes the equivalence of heat and mechanical work. This law states that the heat and work are mutually convertible.

The heat supplied produces external work and cause gain in Internal energy of the body. If “Q” is the heat supplied and “U” is the change in internal energy and “W” is the work done. Then

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

SECOND LAW OF THERMODYNAMICS

It states that ‘There is a definite limit to the amount of mechanical energy, which can be obtained from a given quantity of heat energy’.

According to Clausius, ‘It is impossible for a self-acting machine working in a cyclic process, to transfer heat from a body at a lower temperature to a body at a higher temperature without the aid of an external agency.’

According to Kelvin – Planck, ‘It is impossible to construct an engine working in a cycle, that will produce no other effect than the extraction of heat from a single heat reservoir and the performance of an equal amount of work.’

THIRD LAW OF THERMODYNAMICS

The third law of thermodynamics states that the entropy of a perfect crystal at a temperature of zero Kelvin (absolute zero) is equal to zero.

Entropy, denoted by ‘S’, is a measure of the disorder/randomness in a closed system. It is directly related to the number of microstates (a fixed microscopic state that can be occupied by a system) accessible by the system, i.e. the greater the number of microstates the closed system can occupy, the greater its entropy. The microstate in which the energy of the system is at its minimum is called the ground state of the system.

At a temperature of zero Kelvin, the following phenomena can be observed in a closed system:

- The system does not contain any heat.
- All the atoms and molecules in the system are at their lowest energy points.

Therefore, a system at absolute zero has only one accessible microstate – it’s ground state. As per the third law of thermodynamics, the entropy of such a system is exactly zero.

GAS LAWS

The gas laws are a group of laws that govern the behaviour of gases by providing relationships between the following:

- The volume occupied by a gas.
- The pressure exerted by a gas on the walls of its container.
- The absolute temperature of the gas.
- The amount of gaseous substance (or) the number of moles of gas.

BOYLE’S LAW

Boyle’s law gives the relationship between the pressure of a gas and volume of the gas at a constant temperature. Basically, the volume of a gas is inversely proportional to the pressure of a gas at a constant temperature.

Boyle’s law equation is written as:

$$V \propto 1/P$$

Or

$$P \propto 1/V$$

Or

$$PV = k_1$$

Where V is the volume of the gas, P is the pressure of the gas and K_1 is the constant. Boyle's Law can be used to determine the current pressure or volume of gas and can be represented also as;

$$P_1V_1 = P_2V_2$$

CHARLE'S LAW

Charle's law states that at constant pressure, the volume of a gas is directly proportional to the temperature (in Kelvin) in a closed system. Basically, this law describes the relationship between the temperature and volume of the gas.

Mathematically, Charle's law can be expressed as;

$$V \propto T$$

Where, V = volume of gas, T = temperature of the gas in Kelvin. Another form of this equation can be written as;

$$V_1 / T_1 = V_2 / T_2$$

GAY-LUSSAC LAW

Gay-Lussac law gives the relationship between temperature and pressure at constant volume. The law states that at a constant volume, the pressure of the gas is directly proportional to the temperature for a given gas.

If you heat up a gas, the molecules will be given more energy so they move faster. If you cool down the molecules, they slow down and the pressure decreases. The change in temperature and pressure can be calculated using Gay-Lussac law and it is mathematically represented as;

$$P \propto T$$

Or

$$P / T = k_1$$

or

$$P_1 / T_1 = P_2 / T_2$$

Where P is the pressure of the gas and T is the temperature of the gas in Kelvin.

AVOGADRO'S LAW

Avogadro's law states that if the gas is an ideal gas, the same number of molecules exists in the system. The law also states that if the volume of gases is equal it means that the number of the molecule will be the same as the ideal gas only when it has equal volume. This above statement can be mathematically expressed as;

$$V / n = \text{constant}$$

Or

$$V_1 / n_1 = V_2 / n_2$$

Where V is the volume of an ideal gas and n in the above equation represent the number of gas molecules.

COMBINED GAS LAW

The combined gas law is also known as a general gas equation is obtained by combining three gas laws which include Charle's law, Boyle's Law and Gay-Lussac law. The law shows the relationship between temperature, volume and pressure for a fixed quantity of gas.

The general equation of combined gas law is given as;

$$PV / T = k$$

If we want to compare the same gas in different cases, the law can be represented as;

$$P_1 V_1 / T_1 = P_2 V_2 / T_2$$

IDEAL GAS LAW

Like the combined gas law, the ideal gas law is also an amalgamation of four different gas laws. Here, Avogadro's law is added and the combined gas law is converted into the ideal gas law. This law relates four different variables which are pressure, volume, no of moles or molecules and temperature. Basically, the ideal gas law gives the relationship between these above four different variables.

Mathematically Ideal gas law is expressed as;

$$PV=nRT$$

Where,

V = volume of gas.

T = temperature of the gas.

P = pressure of the gas.

R = universal gas constant.

n denotes the number of moles.

THERMODYNAMIC PROCESS:

The process of heating and expanding of a gas may, broadly, be defined as a thermodynamics process or non-flow process. It has been observed that as a result of flow of energy, change takes place in various properties of the gas such as pressure, volume, temperature, specific energy, specific enthalpy etc.

Some of the important thermodynamics processes are

1. Constant volume process
2. Constant pressure process
3. Isothermal process (constant temperature process)
4. Adiabatic process (or) Isentropic process

CONSTANT VOLUME PROCESS

When a gas is heated at constant volume, its temperature and pressure will increase. There is no change in volume, no external work is done on the gas. All the heat supplied during the process is stored in the body of the gas in the form of internal energy.

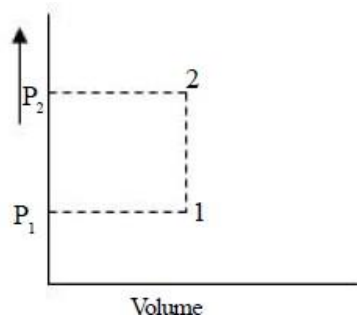


Fig.1.4: P-V Diagram-Constant Volume Process

Work done by the gas = 0

Change in internal energy $E_2 - E_1 = mC_v(T_2 - T_1)$

Where T_1 = initial temperature

T_2 = final temperature

Heat transferred $Q = E + W = mC_v(T_2 - T_1) + 0$

Therefore, $Q = mC_v(T_2 - T_1)$

Relation between P, V and T

$P_1V_1/T_1 = P_2V_2/T_2$

$\therefore P_1/T_1 = P_2/T_2$ (where $V_1 = V_2$)

CONSTANT PRESSURE PROCESS

In this process, when a gas is heated at a constant pressure, its temperature and volume will increase. Since there is a change in its volume, the heat supplied is utilised in increasing the internal energy of the gas and also for doing some external work.

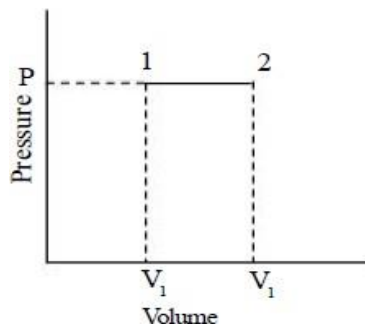


Fig.1.5: P-V Diagram-Constant Pressure Process

\therefore Work done $W = P.dV = P(V_2 - V_1)$ ($\therefore dV = V_2 - V_1$)

Heat supplied to the gas at constant pressure = $mC_p(T_2 - T_1)$

Change in internal energy, $E_2 - E_1 = mC_v(T_2 - T_1)$

Heat transferred $Q = E_2 - E_1 + W$

$\therefore Q = mC_v(T_2 - T_1) + P(V_2 - V_1) = mC_v(T_2 - T_1) + mR(T_2 - T_1)$

Relation between P, V and T

$P_1V_1/T_1 = P_2V_2/T_2$

$\therefore V_1/T_1 = V_2/T_2$ (where $P_1 = P_2$)

CONSTANT TEMPERATURE PROCESS (ISOTHERMAL PROCESS)

In this process temperature remains constant. In this process the whole heat supplied to the gas will be used in doing external work.

Work done $W = P.dV$

But for isothermal process, $PV = P_1V_1$

$$\therefore P = P_1V_1/V$$

$$\therefore W = (P_1V_1/V).dV = P_1V_1.(dV/V) = P_1V_1 \log (V_2/V_1)$$

Change in internal energy $E_2 - E_1 = 0$

Heat transferred $Q = E + W = 0 + P_1V_1 \log (V_2/V_1) = P_1V_1 \log r$.

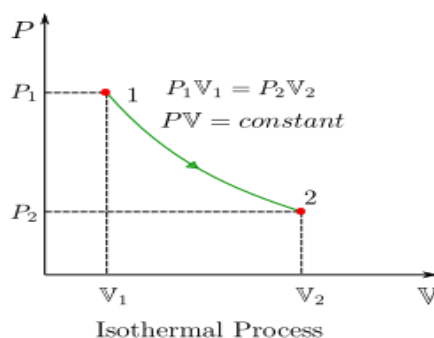


Fig.1.6: P-V Diagram-Isothermal Process

Relation between P, V and T

$$P_1V_1/T_1 = P_2V_2/T_2$$

$$\therefore P_1V_1 = P_2V_2 \quad (\text{where } T_1 = T_2)$$

ADIABATIC PROCESS (OR) ISENTROPIC PROCESS

A process in which the working substance neither receives nor gives out heat to its surroundings, during its expansion or compression is called 'Adiabatic Process'.

During an adiabatic process,

1. No heat enters or leaves in to the working substance.
2. The change in internal energy is equal to work done..
3. The change in internal energy is equal to the mechanical work done.

$$Q = E + W$$

$$0 = E + W \quad (\because Q = 0)$$

$$\therefore E = -W$$

-ve sign indicates work done on a gas

$$\therefore W = (P_1V_1 - P_2V_2)/(\gamma-1)$$

$$= mR (T_1 - T_2)/(\gamma-1) \quad (\text{where } PV = mRT)$$

$$\text{Change in internal energy} = \Delta U = mR (T_2 - T_1)/(\gamma-1)$$

Heat supplied $Q = 0$

Relation between P, V and T

$$P_1V_1^\gamma = P_2V_2^\gamma$$

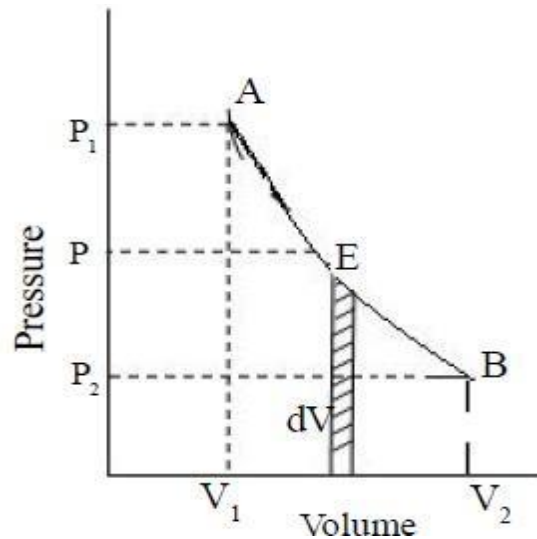


Fig.1.7: P-V Diagram-Isentropic Process

THERMODYNAMIC CYCLES

Thermodynamics cycle consists of a series of thermodynamics processes, which takes place in a certain order and the initial conditions are restored at the end of processes.

Types of Thermodynamics Cycles

Some of the important thermodynamic cycles are

1. Carnot cycle
2. Sterling cycle
3. Otto cycle
4. Diesel cycle
5. Joule Cycle

CARNOT CYCLE

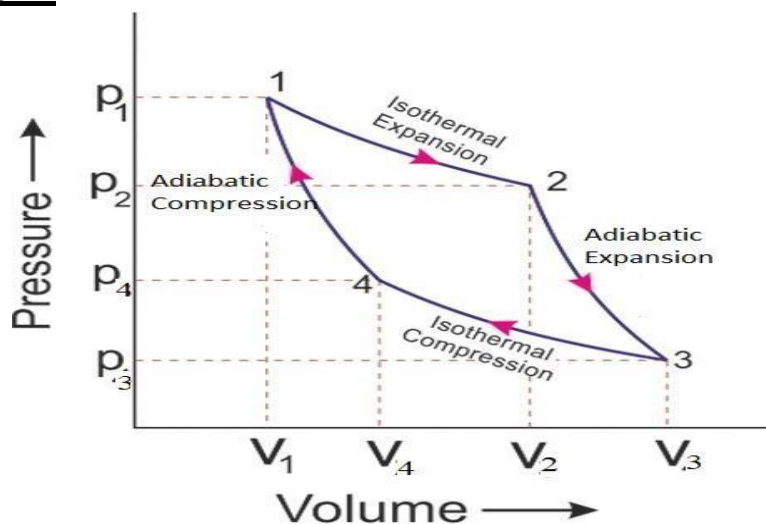


Fig.1.8: P-V Diagram-Carnot Cycle

This cycle consists of two isothermal and two adiabatic operations. From the P-V diagram:

- 1-2 : Isothermal expansion. In this process heat is supplied.
- 2-3 : Adiabatic expansion. In this the heat is used for expansion of the gas.

3-4 : Isothermal compression. In this process heat is rejected from the substance.

4-1 : Adiabatic compression. In this the gas is compressed so that temperature of the substance is increased.

Heat supplied (in process 1-2 isothermally)

$$= P_1 V_1 \log r = RT_1 \log r$$

Heat rejected (in process 3-4 isothermally)

$$= P_3 V_3 \log r = RT_3 \log r$$

\therefore Work done = heat supplied – heat rejected

\therefore Efficiency of the cycle = Work done/Heat supplied

$$= (\text{heat supplied} - \text{heat rejected}) / \text{heat supplied}$$

$$= (RT_1 \log r - RT_3 \log r) / RT_1 \log r$$

$$\text{Efficiency} = 1 - (T_3/T_1)$$

OTTO CYCLE

This cycle consists of two Adiabatic process and two constant volume process. From P-V diagram:

1-2 : Adiabatic compression. The gas is compressed adiabatically.

2-3 : Constant Volume process. Heat supplied in this process.

3-4 : Adiabatic expansion. The gas is expanded adiabatically.

4-1 : Constant volume process. Heat rejected in this process.

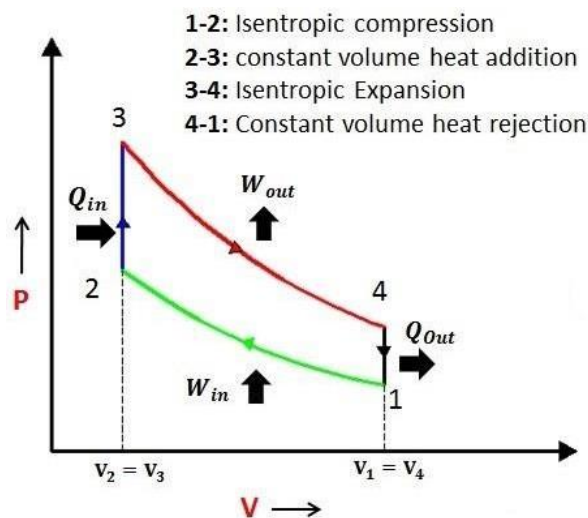


Fig.1.9: P-V Diagram-Otto Cycle

$$\text{Heat supplied} = C_v (T_3 - T_2)$$

$$\text{Heat rejected} = C_v (T_4 - T_1)$$

$$\begin{aligned} \text{Work done} &= \text{heat supplied} - \text{heat rejected} \\ &= C_v (T_3 - T_2) - C_v (T_4 - T_1) \end{aligned}$$

Efficiency of the cycle η = work done / heat absorbed

$$= [C_v (T_3 - T_2) - C_v (T_4 - T_1)] / C_v (T_3 - T_2)$$

$$= 1 - (T_4 - T_1) / (T_3 - T_2)$$

DIESEL CYCLE

The ideal diesel cycle consists of two adiabatic process, one constant pressure and one constant volume process. From P-V diagram:

1-2 : Adiabatic expansion

2-3 : Constant volume process. In this process heat is rejected.

3-4 : Adiabatic compression

4-1 : Constant pressure process. In this process heat is supplied.

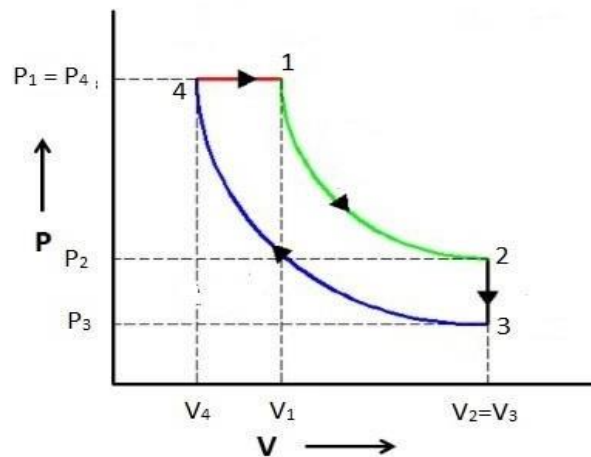


Fig.1.10: P-V Diagram-Diesel Cycle

Heat supplied to the air = $C_p (T_1 - T_4)$

Heat rejected by the air = $C_v (T_2 - T_3)$

Work done = heat supplied – heat rejected

$$= C_p (T_1 - T_4) - C_v (T_2 - T_3)$$

Efficiency of the cycle = Work done/Heat supplied

$$= [C_p (T_1 - T_4) - C_v (T_2 - T_3)] / C_p (T_1 - T_4)$$

$$= 1 - (C_v/C_p) (T_2 - T_3) / (T_1 - T_4)$$

$$= 1 - (1/\gamma) (T_2 - T_3) / (T_1 - T_4) \quad [\text{where } C_p/C_v = \gamma]$$

INTRODUCTION TO FUELS

The substance which produces heat energy on burning with oxygen available in the atmospheric air is called Fuel. The amount of heat generated by the fuel is called its calorific value.

The main constituents of fuel are carbon and Hydrogen which are also called Hydrocarbons. In addition to these elements, the fuels contain small amounts of Nitrogen, Sulphur, Ash and Oxygen.

DESIRABLE QUALITIES OF FUELS

- Posses high calorific Value.
- Emit less smoke.
- Low ash content.
- Should not produce harmful gases on combustion.
- Easy to ignite.
- Easy to control the combustion.

TYPES OF FUELS

The various fuels are classified into three groups.

1. Solid Fuels
2. Liquid Fuels
3. Gaseous Fuels

Each of these fuels are classified into two types

- a) Natural Fuels
- b) Artificial Fuels or Prepared Fuels

SOLID FUELS

The natural solid fuels are wood and coal. The prepared coals are wood char coal, Coke, Briquetted coal and Pulverized coal.

- a. **WOOD:** In the past, wood is used as domestic fuel. Wood contains about 50 % of carbon, 6% of Hydrogen, 42% of Oxygen and about 1 to 2% of ash. It is cheaply available. Wood is not preferred as industrial fuel because of the large amounts of moisture and low. The Calorific value of wood ranges between 3500 kilo cal /Kg to 4000 kilo Cal / Kg.
- b. **COAL:** The vegetation buried in the earth over a long period of time gets transformed into coal. The coal so formed at different stages range from Peat to Anthracite coal.
- c. **PEAT:** Peat is the first stage formation of coal. It contains about 20% of solid and large amount of water up to 80%. It is to be dried for about two to three months before it is used as fuel. It is not considered as industrial fuel due to into low calorific value. The calorific value of Peat is about 5500 K.cal / Kg. which is slightly higher than wood.
- d. **LIGNITE:** Lignite is the second stage formation of the coal. The moisture content is about 40% to 50% and small percentage of carbon. This is also called brown coal as it is brown colour. Lignite is used in thermal power generation, and fertilizer manufacturing. Its calorific value is 6000 K.cal / Kg.
- e. **BITUMINOUS COAL:** It is represented the third stage formation of coal. This coal contains about 70 to 90% of carbon and 20 to 30% of volatile matter and about 4 to 6% of moisture. This coal is used for making coal gas, metallurgical coke and as fuel in Boilers. For steam generation, it burns with yellow flames. The calorific value of Bituminous coal is 8000 K.Cal/ Kg.
- f. **ANTHRACITE COAL:** It is the last stage formation of Coal. It contains about 90 to 98% of carbon with little volatile matter. It burns without smoke. It possesses high calorific value of about 8500 K.Cal / Kg. It is suitable for use in steam generating units.
- g. **WOOD CHARCOAL:** It is made by burning wood with limited supply of air to a temperature of 280°C. It contains about 80% carbon and low ash content. It is most widely used as metallurgical purposes.

- h. **COKE:** Coke is obtained by heating coal in the absence of air for about 45 hours at a temperature of 100°C . This process of burning the air in the absence of air is called carbonization of coal. Coke contains about 90% Carbon, small quantities of Hydrogen, Sulphur, Nitrogen and Phosphorus. The calorific value of coke is 8500 K.Cal / Kg. It is used in blast furnace to extract Pig Iron from Iron ore.
- i. **BRIQUETTED COAL:** The fine powder of coal or coke is made into Briquettes by compressing the material under pressure. Briquetted coals are used in certain applications.
- j. **PULVERISED COAL:** Coals which have high ash content are made into powder. This is done to make use of the maximum amount of burnable substance in the coal. This is called pulverised coal.

ADVANTAGES OF SOLID FUELS

- Cheaper than other fuels.
- Risk of fire is minimum.
- Coal is the raw material for producing coke. Producer gas, Water gas.

LIMITATIONS OF SOLID FUELS

- Requires large amount of storage space.
- Control of Heat is difficult.
- Contains incombustible matter.
- Handling is not easy.
- Properties are not uniform.

LIQUID FUELS

Almost all commercial liquid fuels are derived from natural petroleum (or crude oil). The crude oil is obtained from bored holes in the earth's crust in certain parts of the world. The liquid fuels consist of hydrocarbons.

The natural petroleum may be separated into petrol or gasoline, paraffin oil or kerosene, fuel oils and lubricating oils by boiling the crude oil at different temperatures and subsequent fractional distillation. Some liquid fuels are also obtained from coal (coal tar etc). The following are some of the important liquid fuels:

- a. **PETROL OR GASOLINE:** Petrol is the lightest and most volatile liquid fuel. It is mostly used as fuel for petrol engines, aircraft engines (aviation petrol). It is distilled at temperature from 65°C to 220°C . Its calorific value is 11,000 k.Cal/kg and above.
- b. **KEROSENE OR PARAFFIN OIL:** It is obtained by fractional distillation of

crude oil between 220°C and 345°C. It is used as fuel for some stationary engines etc.

- c. **DIESEL:** It is obtained by straight distillation of several crude oils. It is used as fuel for diesel engines.
- d. **HEAVY FUEL OIL:** It is obtained by distillation of crude oil between 200°C to 360°C. These oils are mostly used in steam power plants, heating furnaces and in diesel engines also. It is distilled at a temperature from 345°C to 470°C.

MERITS AND DEMERITS OF LIQUID FUELS

Following are merits and demerits of liquid fuels over solid fuels.

a) Merits:

- i) Higher calorific value.
- ii) Lower storage capacity.
- iii) Better economy in handling.
- iv) Better content of consumption by using valves.
- v) Better cleanliness and freedom from dust.
- vi) Practically no ashes
- vii) Non-corrosion of boiler plates.
- viii) Higher efficiency.

b) Demerits:

- i) Higher cost
- ii) Greater risk of fire
- iii) Costly containers are required for storage and transport.

GASEOUS FUELS

The natural gas is usually found in or near the petroleum fuels, under the earth's surface. It consists of marsh gas or methane (CH_4) together with small amounts of other gases such as ethane (C_2H_6), carbon dioxide (CO_2) and carbon monoxide (CO). The common example of manufactured gases are Coal gas, producer gas, water gas, mond gas, coke oven gas and blast furnace gas.

a. NATURAL GAS

Natural gas is found in the petroleum fields under the earth's surface. It consists of methane (CH_4) and ethane (C_2H_6) together with small amounts of hydrogen sulphide, carbon dioxide and nitrogen.

b. COAL GAS

It is obtained by destructive distillation of bituminous coal in a fire clay retort. It consists of carbon monoxide, carbon dioxide, hydrogen and

methane. It is used in boilers, gas engines, and also for lighting and heating applications.

c. PRODUCER GAS

It is obtained by partial burning of coke in a mixed air stream blast. It consists of hydrogen. It is mainly used in power generation and glass melting furnaces.

d. WATER GAS (BLUE GAS)

It is produced by blowing the steam through red hot coal or coke. It consists of carbon monoxide and hydrogen along with small amounts of carbon dioxide and nitrogen.

e. MOND GAS

It is produced by passing air and large amount of steam over water coal at 650°C. It is used in furnaces, gas engines and for heating purposes.

f. COKE OVER GAS

It is a by-product from coke over and is obtained by the carbonization of bituminous coal. It is used for industrial heating and power generation.

g. BLAST FURNACE GAS

It is a by-product in the production of pig iron in the blast furnace. It is used as fuel in steel works; for power generation; in gas engines; for steam raising in boilers and for pre-heating the blast furnace.

MERITS AND DEMERITS OF GASEOUS FUELS

i. MERITS:

1. As the supply of fuel gas can be controlled by operating valves; temperature of the furnace can be controlled easily and accurately.
2. These gases are directly used in internal combustion engines.
3. They are free from liquid and solid impurities.
4. They do not produce ash or smoke.
5. Minimum air is needed for their complete combustion.

ii. DEMERITS:

1. They are readily inflammable.
2. They require large storage capacity.

CALORIFIC VALUE OF FUELS

The calorific value or heat value of a solid or liquid fuel may be defined as the amount of heat given out by the complete combustion of '1kg' of fuel. It is expressed in terms of k.Cal/kg of fuel. However, the calorific value of

gaseous fuels is expressed in terms of k.Cal/m³ at a specified temperature and pressure.

These are two types of calorific values of fuels:

- i) Gross or Higher calorific value.
- ii) Net or Lower calorific value.

i. GROSS OR HIGHER CALORIFIC VALUE

All fuels usually contain some percentage of hydrogen when a given quantity of fuel is burnt, some heat is produced. Moreover, some hot flue gases are also produced. The water content of the fuel is converted into steam. If the heat is recovered from the flue gases and the steam is condensed from the flue gases and the steam is condensed back to water at room temperature (i.e. 15°C), then the amount of total heat produced per kg is known as Gross or Higher Calorific value.

In other words, 'the amount of heat obtained by the complete combustion of 1kg of fuel, when the products of the combustion are cooled down to the temperature of supplied air of 15°C is called Gross or Higher Calorific value of fuel'. It is briefly written as H.C.V.

ii. NET OR LOWER CALORIFIC VALUE

When the heat absorbed or carried away by the products of combustion is not recovered and the steam formed during combustion is not condensed, then the amount of heat obtained per kg of the fuel is known as Net or Lower Calorific value of the fuel. It is briefly written as L.C.V.

If the H.C.V. is known, then the L.C.V. may be obtained by subtracting the amount of heat carried away by the products of combustion from H.C.V.

Therefore $L.C.V. = H.C.V. - \text{Heat of steam formed during combustion.}$

The amount of heat per kg of steam in latent heat of steam is 586 k.cal/kg, and the amount of steam formed in 9H₂.

Therefore $L.C.V. = H.C.V. - (9H_2 \times 586) \text{ k.Cal/kg.}$

In SI units, the corresponding relation is $L.C.V. = H.C.V. - (9H_2 \times 2442) \text{ k.Cal/kg.}$

Short Answer Questions

1. Define Thermodynamic system.
2. Explain intensive and extensive properties.
3. Define pressure.
4. Define specific volume.
5. Explain internal energy.
6. Explain Zeroth law of thermodynamics.
7. Define fuel and write the constituents in the fuel.
8. Explain calorific value of the fuel.
9. Write any two merits and demerits of liquid fuels.
10. Write any two merits and demerits of gaseous fuels.
11. Draw the P-V diagram of constant volume process.

Long Answer Questions

1. Explain and derive all expressions for Isothermal process.
2. Explain and derive all expressions for Adiabatic process.
3. Explain the Carnot cycle with P-V diagram and derive efficiency of the cycle.
4. Explain the Otto cycle with P-V diagram and derive efficiency of the cycle.
5. Explain the Diesel cycle with P-V diagram and derive efficiency of the cycle.
6. Write the types of fuels and explain them.