Chapter

5

Heat and Thermodynamics

5.1 INTRODUCTION TO THERMODYNAMICS

Thermodynamics is one of the main branches in physics and engineering. It is also dealing on the study and application of the thermal energy which is also called internal energy of systems. One of the major concepts of thermodynamics is temperature and its measurements. To understand better, we need know thermal properties of matters and the processes.

Generally, in physics we need to know the notions of heat, temperature, work, etc. for betterment of knowledge on thermodynamics. At first, it was considered as a fine invisible fluid that filling up the pores of a material. When a hot body and a cold body are placed together, the form of energy is transferred from hot body to cold body till it become hot. This form of energy is called heat and it is also valued in calories.

Heat: Heat is the form of energy transferred between systems and it is mainly due to a temperature difference between them. According the law of conservation of energy, heat is conserved which means it cannot be created or destroyed. But it can be transferred from one place to another and can also be converted to one from other forms of energy.

For example, a light bulb can be used in that conversion takes place from electrical energy to electromagnetic radiation energy, called light and when this energy is absorbed by any of surface with matter that convert it into a heat. So, energy cannot be destroyed.

Temperature: When the heat energy is become measurable and quantified by changing it average kinetic energy of molecules of matters, then it is called temperature and it is a measurable physical property of matters. The amount of heat transferred by a substance depends on the speed and number of atoms or molecules in motion. The faster the atoms or molecules move, the higher the temperature, and the more atoms or molecules that are in motion, the greater the quantity of heat they transfer. It is measured in Celsius ($^{\circ}$C), kelvin (K), Fahrenheit ($^{\circ}$F), or Rankine (R)

5.2 THERMAL EQUILIBRIUM

A very important concept of thermodynamics is thermodynamic equilibrium. In general, the term equilibrium means in mechanics that the net external force and torque on a system is zero. But the term 'equilibrium' in thermodynamics mentions about the state of a system. The state of equilibrium of system that do not change in time. For example, a gas inside a closed chamber which is completely insulated from the surroundings with constant pressure, volume, temperature, and mass. This state does not change with time, is in a state of thermodynamic equilibrium.

5.3 LAW OF THERMODYNAMICS

There are four laws of thermodynamics which define the fundamental physical quantities such as temperature, energy, and entropy of a system at thermal equilibrium. These laws define the quantities and how it behaves under various circumstances.

The four laws of thermodynamics are:

i. Zeroth law of thermodynamics
ii. The first law of thermodynamics
iii. The second law of thermodynamics
iv. The third law of thermodynamics

5.3.1 Zeroth Law of Thermodynamics

Let us consider the two systems P and Q that are separated by an adiabatic wall (*heat does not enter or leave the wall of system, mentioned blue colour*), when these systems are in contact with a third system or equilibrium with *R* through a conducting wall (*green colour*) as shown in Fig. 5.1a. The states of macroscopic variable of P and Q will be altered when in contact with R. If the adiabatic wall is replaced with conducting wall and R is insulated from P and Q with adiabatic wall as shown in Fig. 5.1b. At this state, P and Q found to be in thermal equilibrium with each other. This process is called as basis of the zeroth law of thermodynamics, which states that *two systems in thermal equilibrium with a third system separately are in thermal equilibrium with each other*. This law helps define the notion of temperature.

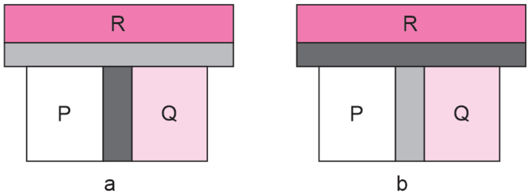

Fig. 5.1: Zeroth law of thermodynamics

5.3.1.1 Heat and Internal Energy

The zeroth law of thermodynamics is directed us to understand better about the concept of temperature. Temperature is a tool to determine the hotness of a body and the flow of heat when two bodies are in thermal contact. Usually, heat can transfer from at high temperature region to the lower temperature. When these two bodies are at equilibrium, the flow of heat stops.

The notion of internal energy of system can be explained with a large number of molecules in a bulk system. The internal energy which is the sum of the kinetic energy and potential energy of these molecules are sharing energy with a condition of centre of mass of the system is at rest in the frame of reference. But the internal energy of the system is depending on the state of the system and it does not depend on how the state of system formed.

5.3.2 First Law of Thermodynamics

The first law of thermodynamics, also known as law of conservation of energy which states that energy can neither be created nor to be destroyed; energy can only be transferred or changed from one form to another. For example, if you switch on a light, it would produce energy where its electrical energy is converted.

The first law of thermodynamics can be expressed in the form of energy that any change in the internal energy (°E) of a system is given by the sum of the heat (Q) that flows across its boundaries and the work (W) is done on the system by its surroundings:

therefore, $$\Delta E = Q + W \quad ...(5.1)$$

from the above equation, there are two kind of process, heat and work, which can lead to a change in the internal energy of the system. Since both heat and work can be measured quantitatively. According to the interrelation between heat and work, any change in the energy of a system must result in a corresponding change in the energy of the surroundings that outside of system. In other words, energy cannot be created or destroyed. If heat flows into a system or the surroundings do work on it, the internal energy increases and the sign of Q and W are positive. On the other words, heat flow out of the system or work is done by the system (on the surroundings) and it will be expressed as the internal energy of the system so that Q and W will be negative.

5.3.2.1 Specific Heat Capacity

If a small amount of heat ΔQ is given to a substance that produces a changes in small amount of temperature ΔT of substance. Then the final temperature of substance is $T + \Delta T$. It can be expressed as follows.

$$S = \frac{\Delta Q}{\Delta T} \quad ...(5.2)$$

The amount of heat given to a substance will be vary with its mass. So, the heat capacity S is also proportional to the mass of the substance and in addition it is depending on temperature, i.e. a different quantity of heat may require to increase the temperature of substance. To define a constant of specific heat of substance and independent of its amount, S could be expressed as,

$$S = \frac{S}{m} = \left(\frac{1}{m}\right)\frac{\Delta Q}{\Delta T} \quad ...(5.3)$$

From the above equation, S is known as the specific heat capacity of the substance. It may vary depend on the nature of the substance and its temperature. The unit of specific heat capacity is $J\ \mathrm{kg}^{-1}\ \mathrm{K}^{-1}$.

If the amount of substance is expressed in terms of moles μ, so heat capacity per mole of the substance is given by

$$C = \frac{S}{\mu} = \frac{1}{\mu}\frac{\Delta Q}{\Delta T} \quad ...(5.4)$$

C is known as molar specific heat capacity of the substance. If C is independent of the amount of substance, but it depends on the nature of the substance, its temperature and the conditions in which heat is supplied. So that the unit of C can be expressed as $J\ \mathrm{mol}^{-1}\ K^{-1}$.

From the Eq. (5.3) the specific heat capacity of substance, defined as "the amount of heat is required to raise the temperature of 1 gram of substance by 1°C."

Thus, specific heat values of a substance can be determined by a small practice, take two materials of different temperatures which are placed together in contact. As we know, the heat flows from the higher temperature region to the lower temperature region of material. According to the law of conservation of energy, the heat lost in the material is equal to the same heat that gained by the another material. Based on that, heat gained by the material that has increase in temperature which is equal to the temperature that lost by another substance in contact. It is also observed that heat gained by the substance may vary in difference in temperature and substance. So different substances have different specific heat and heat capacity S of a substance is the quantity of the heat required to raise the temperature of the whole substance by one degree. If the mass of the substance is unity then the heat capacity is called specific heat capacity or the specific heat.

From Eq. (5.3) and (5.4), specific heat capacity formula is given by

$$Q = Cm\,\Delta T \quad ...(5.5)$$

Where

Q = quantity of heat absorbed by a body

m = mass of substance

T = rise in temperature

C = specific heat capacity of a substance depends on the nature of the material of substance. SI unit of specific heat is J kg^{-1} K^{-1} *(mass is kg not in mole).*

5.3.2.2 Thermodynamic State Variables and Equation of State

The word equilibrium in thermodynamics is described by precise values of some macroscopical variables, called state variables. For example, in gas thermodynamically, an equilibrium state of a gas is stated by the different values of pressure, volume, temperature, mass and also its composition.

At the same time, a thermodynamical system is not always in equilibrium. In case, if a gas allowed it to expand freely which is not an equilibrium state. This is due to rapid expansion of gas that produce a state of non-equilibrium. Similarly, if the pressure and temperature are not uniform in the chemical reaction of a mixture of gases which undergoes an explosion. Later, the mixture of gas reaches the state of uniform temperature and pressure and comes to thermal and mechanical equilibrium with its surroundings as shown in Fig. 5.2.

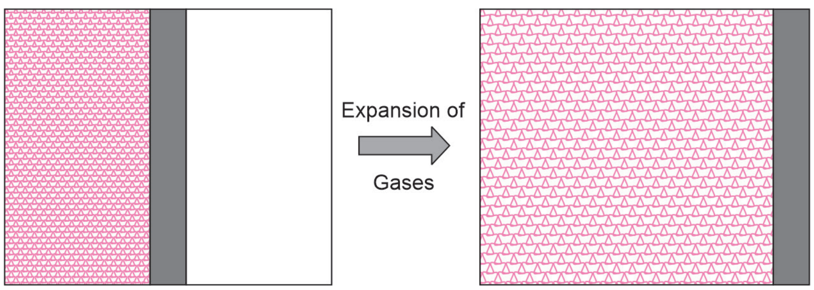

Fig. 5.2: State of thermodynamic system

5.3.2.3 Thermodynamic Processes

In thermodynamics, a process in which heat energy is transferred within a system or in between systems is called thermodynamic processes.

There are four types of thermodynamic processes. These are also classified into group process called pairs in which each variable held constant and one is a conjugate pair.

Pressure–volume:
(1) Isobaric and (2) Isochoric

Temperature–entropy:
(1) Isothermal and (2) Adiabatic

1. **Isobaric process:** A thermodynamic isobaric process occurs when pressure is maintained at constant. For example, a movable piston in a cylinder that the system is dynamically connected, by a movable boundary, to a constant-pressure reservoir.
2. **Isochoric process:** A thermodynamic isochoric process occurs when volume is maintained at constant. The resultant mechanical PV work done by the system will be zero. So it is also called an isometric process or constant-volume process. The term isochoric means "iso"—"constant" and "choric"—"space" or "volume." Where pressure and volume maintained constant.

   For example, in a closed tin box placed into a fire. In that instant, the tin box will not expand, and the only change is gaining in internal energy, this causes increase in temperature and pressure inside the tin where the volume is maintained at constant.

   Mathematically it is defined as,

   $$\delta Q = dU \qquad \text{...(5.6)}$$

   From the above equ (5.1), the total heat given or rejected is also equal to the increase or decrease in the internal energy of the system.
3. **Isothermal process:** A thermodynamic isothermal process occurs only when the temperature is kept constant as the pressure increases during compression. At the same time, it is not possible to build a device that will compress isothermally, isothermal performance is attained only when the number of intercoolers or other cooling devices is increased. In practice, isothermal compression cannot be attained because if a system is in contact with a thermal reservoir from outside, then, to maintain thermal equilibrium, the system slowly adjusts itself with the temperature of the reservoir through heat exchange. That means during an isothermal process there is a change in internal energy, heat energy, and work, even though the temperature remains the same.

   For an ideal gas, $$PV = nRT \qquad \text{...(5.7)}$$

   where, n = no. of moles (constant),

   R = universal gas constant,

   T = constant for isothermal process.

   Therefore, from Eq. (1), PV = constant.
4. **Adiabatic process:** A thermodynamic adiabatic process in which there is no exchange of heat from the system to its surrounding neither expansion nor compression. It means the process can be either reversible or irreversible. The essential conditions for the adiabatic process are as follows:
   a. The system should be insulated from the surrounding.
   b. The process must be carried out quickly so that there is enough time for heat transfer to take place.

5.3.2.4 Heat Engines

It is a type of device that helps to convert heat to work in which system is made to undergo a cyclic process. For example, in a system with a mixture of fuel vapor and air in an engine are the working substances of that system. There are several processes on working substance which undergoes through a cycle. In some of these processes, it absorbs a total amount of heat Q_1 from an external reservoir at some high temperature T_1. In some other processes of the cycle, the working substance releases a total amount of heat Q_2 to an external reservoir at some lower temperature T_2.

The system work done (W) in a cycle is transferred to the environment through a moving piston in a cylinder that transfers mechanical energy to the wheels of a vehicle via a shaft. The features of a heat engine are shown in Fig. 5.3.

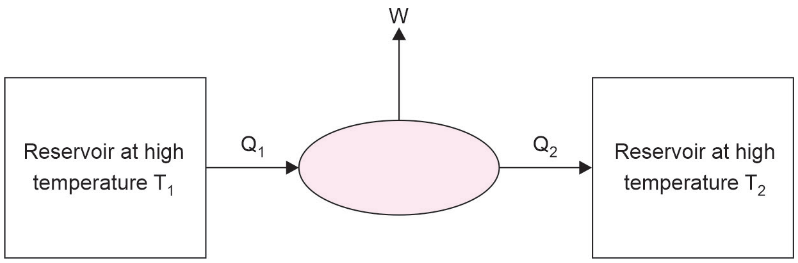

Fig. 5.3: Schematic diagram of heat engine

The efficiency (η) of a heat engine is defined by

$$\eta = \left(\frac{W}{Q_1}\right) \qquad \text{...(5.8)}$$

where, Q_1 is the heat input, i.e. the heat absorbed by the system in one complete cycle and W is the work done on the environment in a cycle. In a cycle, a certain amount of heat (Q_2) may be rejected to the environment. Then, according to the first law of thermodynamics, over one complete cycle,

$$W = Q_1 - Q_2 \qquad \text{...(5.9)}$$

$$\therefore \qquad \eta = 1 - \left(\frac{Q_2}{Q_1}\right)$$

If $Q_2 = 0$, which means amount of heat rejection is zero, then the engine will have 100% efficiency in converting heat into work. Note that the first law of thermodynamics, i.e. the energy conservation law does not rule out such type of an engine. But some expertise experience assumed that such an ideal engine with $\eta = 1$ which is never possible, even if well suited eliminate with various kinds of losses associated with actual heat engines. It turns out that there is a fundamental limit on the efficiency of a heat engine set by an independent principle of nature, called the second law of thermodynamics.

5.3.3 Second Law of Thermodynamics

The second law of thermodynamics states that *the entropy of any isolated system always increases. Isolated systems spontaneously evolve towards thermal equilibrium—the state of maximum entropy of the system. More simply, the entropy of the universe (the ultimate isolated system, i.e. randomness) only increases and never decreases.*

For example, the second law of thermodynamics (*see* Subsection 1.7.3) can be understood with the rooms of a person, if not gutted and neatened, will habitually become more disordered and unsystematic with time-regardless of how careful one is to keep it clean. When the room is cleaned, its entropy decreases, but the effort to clean it has resulted in an increase in entropy outside the room that exceeds the entropy lost. Simply randomness in the room decides the entropy.

Kelvin-Planck statement: No process is required whose individual result is the absorption of heat from a reservoir and the complete conversion of the heat into work.

Clausius statement: No process is required whose individual result is the transfer of heat from a colder object to a hotter object. It can be proved that the two statements above are completely equivalent.

5.3.3.1 Reversible and Irreversible Processes

If the processes are said to be reversible the changes in the process will back to initial stage, whereas in irreversible process the changes will not back to initial stage. For example, when a water evaporates from its liquid state to gaseous state and it will back to initial stage by its condensation reaction and forms rain. So reversible process is the natural and ideal process. In case if you break a glass into a piece and this will not back to initial stage. This is irreversible process.

Reversible process: In a thermodynamical system a process, the reversible and it will return to initial state of both the system and the surroundings. It means both system and surroundings are returned to their initial states at the end of the reverse process.

Figure 5.4 shows the depiction of system process which undergoes a change from its state 1 to 2. If the system changes thermodynamically from 1 to 2 that are equilibrium with each other. Similarly, from state 2 to 3 and to 4 and finally, it returns to its original state where all the state should be thermodynamically equilibrium with each other.

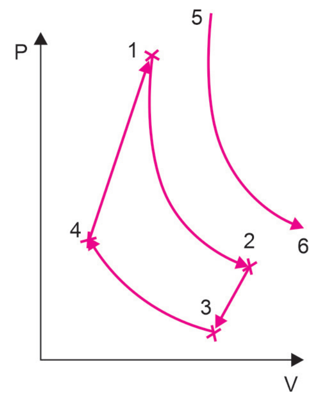

Fig. 5.4: A thermodynamic process—reversible and Irreversible

Irreversible process: From the Fig. 5.4, the system undergoes a change from its state 5 to 6 and it is not back to 5 because of deviated from equilibrium state. In this case, irreversible process occurs as a result of straying away from the curve and not back to initial state. An irreversible process is a thermodynamic process that departs from equilibrium. In terms of pressure and volume, it occurs when the pressure (the volume) of a system changes dramatically and instantaneously that the volume (the pressure) does not have the time to reach equilibrium.

5.3.4 Third Law of Thermodynamics

The third law of thermodynamics states that *the entropy of a system approaches a constant value as the temperature approaches absolute zero*. At absolute zero temperature, the entropy of a system is typically zero and the number of different ground states in a system determined in all cases. For example, the entropy of a pure crystalline substance (perfect order) at absolute zero temperature is zero. This statement holds true, if the perfect crystal has only one state with minimum energy.

5.4 THERMOMETRY

Thermometry in physics is a branch which deals with the measurement of temperature and the device used to measure this temperature is called thermometers. To understand the concept and its technique in thermometry, few basic things that we need to know.

Heat: Heat is one form of energy which is also called thermal energy that flows from a region of higher temperature of body to a region of lower temperature of body. This will occur only when both are in contact with each other.

The process of translational, vibrational and rotational motion effect on heat or thermal energy of a body which is the sum of kinetic energies of all its constituent particles. The SI unit of heat energy is joule (*J*) but in practice the thermal energy can be measure in the unit in calorie.

$\therefore$ 1 cal = 4.18 *J* which mean 1 calorie of heat energy is required to raise the temperature of 1 g of water to raise in temperature of 1 °C.

Temperature: Temperature is defined as the degree of hotness or coldness of the body. A device which is used to measure the temperature, is called a thermometer. It is the property that determines the thermal equilibrium of body with it neighboring system. This thermal equilibrium property can be expressed in a numerical value called temperature.

Highest possible temperature accomplished in laboratory is about 108 K, whereas lowest possible temperature is 108 K. If the temperature close to 0 K is known as cryogenics and if the temperature approaches to very high temperature is called pyromet.

Different Scales of Temperature

Celsius scale: In this scale of temperature, the melting point of ice is considered as 0 °C and the boiling point of water as 100 °C and space between these two points is divided into 100 equal parts

Fahrenheit scale: In this scale of temperature, the melting pointing of ice is considered as 32 °F and the boiling point of water as 211 °F and the space between these two points is divided into 180 equal parts.

Kelvin scale: In this scale of temperature, the melting point of ice is considered as 273 °K and the boiling point of water as 373 K the space between these two points is divided into 100 equal parts.

Relation between different scales of temperatures

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100} = \frac{R}{80}$$

Types of Thermometers

1. Gas thermometer
2. Liquid thermometer
3. Magnetic thermometer
4. Radiation thermometer
5. Resistance thermometer
6. Thermoelectric thermometer

5.5 THERMOSTAT

Thermostat is a device which can be used to control and regulate temperature in desired level in different devices. It works on the principle of thermal expansion.

Thermal expansion: It is defined as the alterations of the length, width, height, or volume of any type of material on changing its temperature. It can be easily seen in solids where atoms are tightly packed. It has lot of applications in our day-to-day life. According to this phenomenon substances will be expanded on heating and condensed on cooling.

Working: It works on the general principle of thermal expansion. Based on the expansion or condensation of material governs the switching off or on of the electric circuit. There are different mechanisms of thermostats are in use and the most common types of mechanical thermostats are either bimetallic strips or bellows filled with gas. Whereas the digital thermostats use the same principle, but everything is controlled by a integrated circuits, chips and built-in minicomputer.

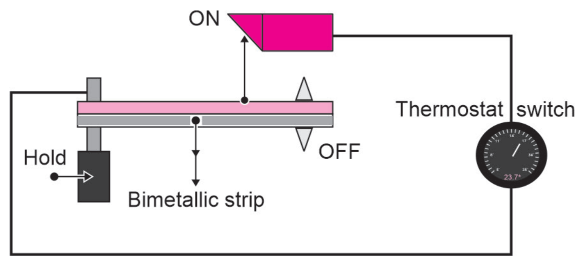

Fig. 5.5: Schematic diagram of thermostat

Bimetallic strips: Bimetal, the name indicates that the thermostat has two pieces of metals which are varying with its coefficients of expansion but are connected to each other and form a bimetallic strip. This behaves like a bridge to connect or disconnect the electric circuit of the heating or cooling system. When it gets down that causes the heating due to the bimetallic strip conducts current and the system starts like switch on. In this case, the strip gets hot that cause one of the metal pieces to get hotter than the other. The hotter strip expands, causing to break the circuit, the heating or cooling (strip) switches is now off. During this state no current through the bimetallic strip, so the metal starts to cool down gradually which means the expanded metal piece starts condense to its original size. At the end, the heating or colling restarts as shown in Fig. 5.5.

Advantages
- Easy to handle and not required power source.
- Highly efficient and active device.
- Simple and economy.
- Suitable for a wider range of temperature (<450 °C).

Disadvantages
- Less accurateness.
- Not appreciated in industrials.
- Not suitable for very low temperature.

Types of thermostat
1. Bimetallic strip thermostat
2. Capillary thermostat
3. Digital thermostat
4. Smart thermostat
5. Wax type thermostat

5.6 THERMOCOUPLE

It is a type of device which is used to measure temperature at one point. This thermocouple has a sensor that is used for measuring the temperature in the form of an electric current or the EMF. It consists of two wires of different metals and are soldered together at the ends. The soldered portion is created junction where the temperature is measured. The variation in temperature of the wire induces the voltages and it is recorded with suitable device to display the temperature at one point.

Construction and working of thermocouple: The thermocouple consists of two dissimilar metals. These metals are welded together at the junction points P and Q. This junction considers as the measuring point. The junction point categorizes into three types.

i. Ungrounded junction
ii. Grounded junction
iii. Exposed junction

Three types of effects are playing a major role in the working principle of the thermocouple.

5.6.1 Seebeck Effect

According to this effect, two different metals are involved where the heat is provided to any one of the metals, the electrons start flowing from hot metal to cold metal. The seebeck effect occurs between two different metals. When the heat provides to any one of the metals, the electrons start flowing from hot metal P to cold metal Q. Thus induces direct current in the circuit.

Seebeck effect states that *the temperature differences between the two different metals induces the potential differences between them.* This causes flow of electrons between plates producing small voltages.

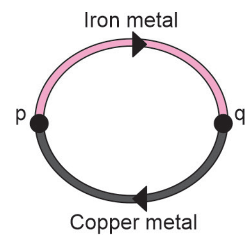

Fig. 5.6: Seebeck effect

5.6.2 Peltier Effect

The Peltier effect is the inverse of the seebeck effect. The Peltier effect states that *the temperature difference can be created between any two different conductors by applying the potential difference between them.*

5.6.3 Thompson Effect

The Thompson effect states that *when two dissimilar metals join together and if they create two junctions then the voltage induces the entire length of the conductor because of the temperature gradient.* The temperature gradient is a physical term which shows the direction and rate of change of temperature at a particular location.

Advantages of Thermocouple

1. The thermocouple is cheaper than the other temperature measuring devices.
2. The thermocouple has the fast response time.
3. It has a wide temperature range.

5.7 CALORIMETRY

Calorimetry is a technique that is used to measure the amount of heat absorbed or released in a reaction. A calorimeter is an instrument used in calorimetry and it is also used to determine heat content, latent heat, specific heat, and other thermal properties of substances. Generally, calorimeter readings are in calories.

Principle of calorimetry: Two bodies of different temperatures are kept together in thermal contact then absorption and release of heat take place. According to second law of thermodynamics states that heat flows from the body at higher temperature to the body at lower temperature which receives heat. This flow of heat will continue until they reach at the thermal equilibrium.

If there is no heat lost during absorption and release of heat in a process, then the amount of heat given up by the body at higher temperature will be equal to the heat gained by the body at lower temperature.

$\therefore$ Heat lost = Heat gained

It is called the principle of calorimetry.

Structure and operation of a basic calorimeter: Considered a chamber consists of two vessel which forms a basic calorimeter. This two-vessel chamber has the outer vessel and the inner vessel. The air is maintained between both vessels that act as an insulator of heat and it is also ensuring that heat is not transferred between the contents of the inner and outer vessels.

The calorimeter is also well equipped with a thermometer and a stirrer in which the thermometer is used to measure the temperature of the liquid in the inner vessel and the stirrer is used to distribute heat equally in the vessel. The calorimeter has an insulating cover with holes for the stirring rod and thermometer.

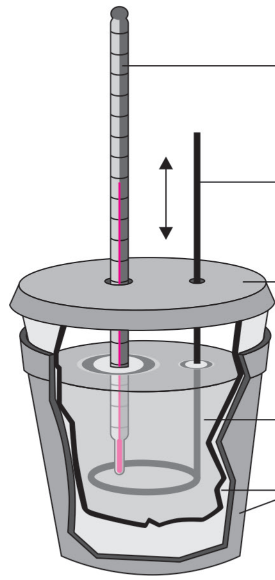

Fig. 5.7: Calorimetry

Working: To measure the specific heat of given material, the inner vessel is now filled with 100 ml water. Later the calorimeter is closed inside the cover for half an hour. At this time, the bulb of the thermometer should be placed in the water. After half an hour, the temperature is read and recorded.

A test tube is half filled with given materials like iron nails or balls. The weight of the material is noted. The filled test tube is now placed in boiling water for 10 minutes. The material is absorb the heat and reach a temperature of 100 °C without getting wet. The calorimeter is opened and the materials are transferred into the inner vessel. The calorimeter is closed immediately after transferred the material.

The temperature of water in the inner vessel is raised because of the heated material and the temperature is noted which is the final temperature of the water and material. The temperature increase of the water and temperature loss of the material is measured.

The temperature increase of water is multiplied by the 100 ml volume of water to calculate the total heat transfer in calories. The total heat transfer is divided by the temperature loss of the iron. Finally, the results are divided by the weight of iron to calculate the specific heat of given material.

Applications: Some of the key application areas of calorimeters are as follows.
- In laboratories like biochemistry and chemistry labs.
- In physics, thermodynamics study.
- In practicals.
- Pharmaceutical and polymer industries.
- Propellant and explosive testing.
- To assess the thermal hazard batteries.
- To study about the thermodynamic properties of different materials like nanomaterial and ceramics.
- To study the liquid crystals properties.

Types of calorimeters: Calorimeters are of many types. Some of the common types are as follows:
- Adiabatic calorimeters.
- Bomb calorimeters (constant volume calorimeters).
- Constant pressure calorimeters.

- Differential scanning calorimeters.
- Reaction calorimeters.

5.8 WATER BATH

It is a type of apparatus that consists of a container filled with heated water. So it can be used to maintain samples in water at a constant temperature for a long period. It is also accommodate with digital or an analogue interface to allow operators to set a required temperature.

It is also used to raise the temperature of reagents, melting of substrates or development of cell cultures. Further, it can be used to enable certain chemical reactions to occur at high temperature. Water bath is a preferred heat source for heating flammable chemicals instead of an open flame to prevent ignition. Different types of water baths are in use based on different applications. 99.9 °C is the ideal temperature for all water baths but in case of temperature above 100 °C, oil bath, silicone bath or sand bath may be used as alternates.

Types of water bath

Circulating water baths: Circulating water bath is used to maintain uniform temperature. It is also called stirrers. The main motive of water bath is ideal for temperature uniformity. Circulator is used to regulate the temperature of water at specific level. In enzymatic and serologic experiments, this type of water bath is very essential and consistency is critical.

Non-circulating water bath: This is the convection type of water bath which is adapted primarily, later it is derelict because water in the water bath is heated uniformly instead of circulating. Therefore, it is less accurate in terms of temperature control. This is considered as disadvantage in this type of water bath and it is modified with stirring to non-circulating water baths to create more uniform heat transfer.

Shaking water bath: The name of the water bath itself implies it function. It has an extra control for shaking, that provides liquids to move around. Even this can be turned on or off. In microbiological practices, constant shaking allows liquid-grown cell cultures grown to constantly mix with the air.

Precautions

- It is moisture sensitive or pyrophoric reactions. Do not heat a bath fluid above its flash point.
- It should be monitored regularly and have to use only distilled water so that it can prevent salts to deposite on the heater.
- Disinfectants can be added to prevent growth of organisms.
- For decontamination process, we have to raise the temperature to 90 °C or higher.
- It should be operated in well ventilated area
- To prevent evaporation and raising temperature, it is always closed.
- Set up on a steady surface away from flammable materials.

5.9 INCUBATOR

An incubator is a device used to grow and maintain microbiological cultures or cell cultures. The main purpose of the incubator is to maintain optimal temperature, humidity and carbon dioxide (CO_2) level and oxygen content inside. It has a vital role in experimental work of cell biology, microbiology, molecular biology, and biotechnology.

Louis Pasteur, a French chemist, and microbiologist who investigate his research on microbial fermentation. He used the small opening underneath his staircase as an incubator for his research. It is often used in the poultry industry to act as a substitute for hens. Nowadays, various brands of incubators are commercially available.

The simplest incubators as shown in Fig. 5.8, are insulated boxes with an adjustable heater, typically going up to 60 °C to 65 °C (140 °C to 150 °F), though some can go slightly higher (generally to no more than 100 °C). The most used temperature bath for bacterial culture such as *E. coli* and other mammalian cells is approximately 37 °C (99 °F), as these organisms grow well under such conditions. For other organisms used in biological experiments, such as the budding yeast, *Saccharomyces cerevisiae*, a growth temperature of 30 °C (86 °F) is optimal.

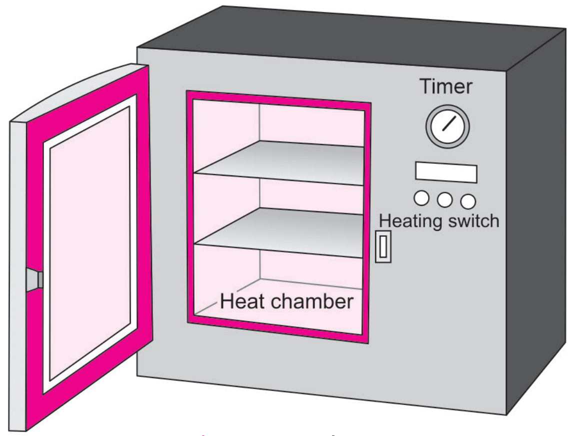

Fig. 5.8: Incubator

More elaborate incubators can also include the ability to lower the temperature (via refrigeration), or the ability to control humidity or CO_2 levels. This is important in the cultivation of mammalian cells, where the relative humidity is typically >80% to prevent evaporation and a slightly acidic pH is achieved by maintaining a CO_2 level of 5%.

Applications

- Breeding of insects and hatching of eggs in zoology
- Controlled sample storage
- Growing cell cultures
- Growing of crystals/protein crystals
- Reproduction of germ colonies and subsequent determination of biochemical oxygen demand (wastewater monitoring)
- Reproduction of germ colonies with subsequent germ count in the food industry
- Reproduction of micro-organisms such as bacteria, fungi, yeast or viruses
- It is also used in other fields like genetic engineering, medical treatments, tissue culture, pharmaceutical studies, hematological studies, biochemical studies, food processing, cell aeration, plant and animal studies, solubility studies, fermentation studies and bacterial culturing.

5.10 AUTOCLAVE

Autoclave is a process of sterilization with the help of steam which is under reduced pressure and temperature above 100 °C. This steam sterilization process is carried out in the chamber called an autoclave.

Construction: This autoclave consists of chamber which is made up of stainless steel and it is also provided with moist heating for sterilization. It has a covered with steam vent, a pressure, and a safety value. To make an air tight inside the chamber, it is provided with rubber gasket. The heating is done in the chamber by an electrical heather, that is, fitted at the bottom. So, it can convert the water to the steam. The steam is supplied to the autoclave chamber where the perforated inner chamber is placed on the stand. The material is sterilized which is loosely packed into it as show in Fig. 5.9.

Principle: The principle of the autoclave is when the vapor pressure of water is equal to that of surrounding atmosphere then the water starts boil. If the pressure inside the closed vessel increases, the temperature of water boils also increases. This is a better condition to sterilize because the saturated steam has better penetrating power.

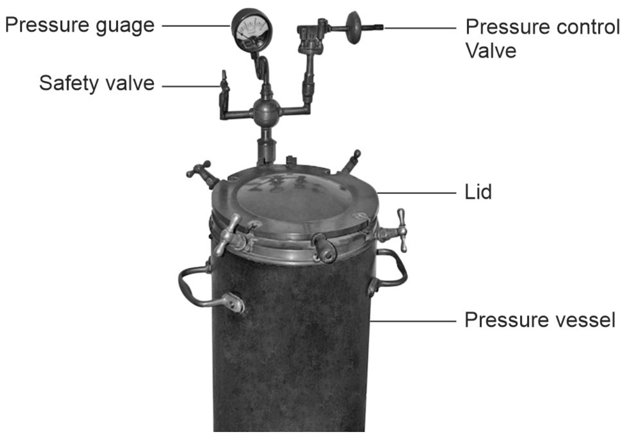

Fig. 5.9: Autoclave

Steam condensed to water and gives up to latent heat to that surface when it comes in contact with the cooler surface. The water of the condensation is ensuring moister conditions for killing of the exposed micro-oraganisms. For example, bacterium is susceptible and this moist heat to bacterial proteins coagulates rapidly and condensed water ensures moist conditions for killing the microbes present.

Working

- Once perforated plate in removed from the chamber, a sufficient amount of water is poured into the chamber. The level of the water is adjusted to avoid the contact between water and perforated plate.
- The lid of autoclave is closed with the wing nuts and bolts. Later the autoclave is a switched onto heat the water. The vent is now opened and safety valve is adjusted to ensure the required pressure.
- Whem steam starts coming out from the vent and it continuous for 5 mins and it is then closed. It indicates that air has been removed. The steam pressure starts raising and it comes to the desired pressure.
- Therefore, 10 lbs per square inch with corresponding temperature 121 °C after the stated period, switch of the autoclave. Allow it to cool to about 40 °C before opening the vent. When whole of the steam inside the autoclave is removed, the lid is opened and the sterilized material is removed.

Type of Autoclave

1. Downward displacement laboratory autoclave
2. High security autoclave
3. Large simple autoclave
4. Low temperature steam
5. Media preparators

6. Multipurpose laboratory autoclave
7. Porous load sterilizers
8. Simple laboratory autoclave
9. Transportable bench top autoclaves

Advantages

1. Autoclave has steam to provide intense heat and moisture for decontaminate objects.
2. It can destroy micro-organisms more efficiently than dry heat
3. In autoclave, the materials are exposed to a lower temperature for a shorter period only.
4. It is used for sterilization of many official injections.
5. Equipment or parts of rubber or plastics which can be withstand the temperature can be sterilized easily.
6. A large quantity of materials can be sterilize.

Disadvantages

1. It is not suited powders and oils.
2. It cannot be used to sterilized of material that not withstand the temperature of 115 °C–116 °C.

5.11 REFRIGERATORS

A refrigerator is type of enclosure that interior temperature is kept lower than surrounding environment. The term "refrigerator" was coined by a Maryland engineer, Thomas Moore, in 1800. Moore's device would now be called an "ice box"

It is worked by passing a cool refrigerant gas around food items that is placed inside and the refrigerant can absorb heat from them and then loses that heat to the relatively cooler surroundings on the outside of the refrigerator.

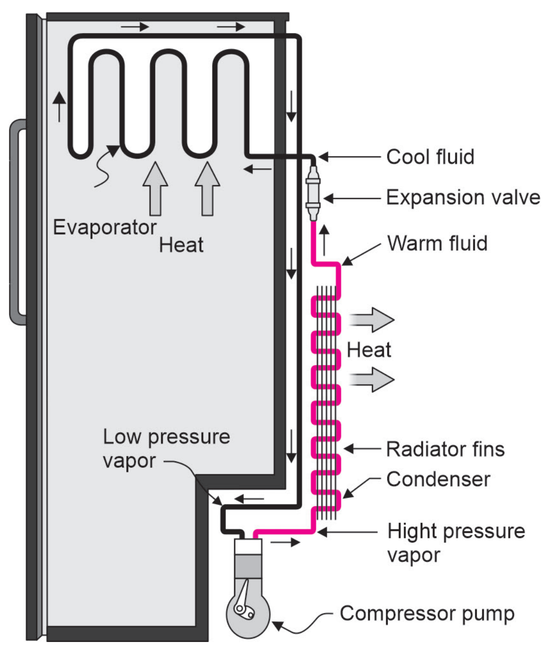

Fig. 5.10: Refrigerator

Refrigerator working principle: The working principle of a refrigerator is very simple. In general, it removes heat from one place and its deposition to another. When you pass a low-temperature liquid close to objects. Heat from those objects is transferred to the liquid, which evaporates and takes away the heat in the process. The gas called refrigerant tends to become hot when it is compressed and become cold when it is expanded, which helps a refrigerator cool the stuff being kept inside always.

Parts of a refrigerator: The following are the parts of a refrigerator and consist of a few key components that play a vital role in the refrigeration process:

Expansion valve: It is also called the flow control device. The flow of liquid refrigerant can be controlled by the expansion valve. Actually, this device is a very small device and it is very sensitive to temperature changes of the refrigerant.

Compressor: The compressor consists of a motor that 'sucks in' the refrigerant from the evaporator and compresses it in a cylinder to make a hot, high-pressure gas.

Evaporator: Evaporator is one of the important parts in refrigerator. It has crooked tubes that helps to absorb heat and blown it out through a coil. It absorbs heat not only from fridge but also from the fold stuff and absorbed heat turns liquid refrigerant into vapor. This will be back to liquid state after release the heat from it.

Condenser coils: The condenser placed outside of refrigerator with external fins or crooked tubes. It helps the liquefication of vaporized refrigerant by releasing the heat to the surroundings. Once the temperature drops then refrigerant tends to condensation and become liquid.

Refrigerant: It is a type of specialized chemical that has ability to become gas by receiving heat and become liquid by release heat. CFCs are commonly called Freon and it is the brand name of R12 which is commonly used as refrigerant. This was later replaced with HCFC called hydrochlorofluorocarbon. The brand name of HCFC is R22. At present various refrigerants/coolants are commercially available now. They are R410A, R22, R32, R290, R134A, R600A. This can be used for both air conditioners and refrigerators

Types of Refrigerators: Depending upon the purpose of usage and application the refrigerator, it can be classified as follows:

1. Commercial refrigeration.
2. Domestic refrigeration.
3. Industrial refrigeration.
4. Marine and transportation refrigeration.