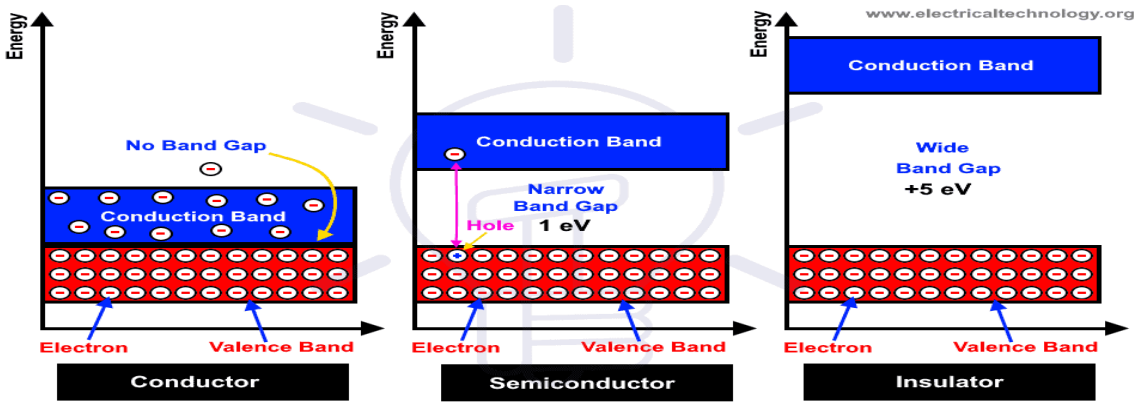
INSULATING MATERIALS

Importance of Insulating Materials

The importance of the insulating materials is ever-increasing in day by day as there is an innumerable number of types of insulators available in the market. The function of the insulator is very important without which no electrical machine can work, the majority of the breakdown in the field of electrical engineering is due to the failure of insulation. The selection of the right type of insulating matter is very important because the life of the equipment depends on the type of material used.



Insulating Material

- Insulating materials are the materials that inhibit heat transmission, electric current, or noise.
- Insulating materials are available in a large variety e.g. mica, ceramics, rubber, glass, paper, porcelain, fibrous, plastic, transformer oil, air, SF6 gas, nitrogen, Freon etc.
- All the insulating materials have a negative temperature coefficient of resistance and as such resistivity is reduced with an increase in temperature.
- Their resistance is usually in Megaohm. They are non - metallic materials of high resistivity.

Properties of Insulating Materials:

- All the insulators when used should not only behave as an insulator over a wide range of electric voltage but must strong mechanically.
- They shouldn't be affected by heat, atmosphere, chemical effects and should be free from deformation due to aging.
- Therefore before selecting an insulating material, it is quite essential to know the various properties and their effects on insulation.
- The various properties of insulating materials are electrical properties, visual properties, mechanical, thermal, and chemical properties.

Thus they should possess

- ✓ High dielectric strength
- ✓ High insulation resistance
- ✓ Low dielectric constant or permittivity
- ✓ Low dielectric loss
- ✓ High mechanical strength
- ✓ High thermal or heat conductivity
- ✓ High degree of thermal stability. It should not be affected by change in temperature
- ✓ It should be uniform throughout.

- ✓ It should be free from gaseous not evaporate.
- ✓ Solid insulating materials should have high melting point.

Classification of Insulating Materials

Insulating materials used in electrical machines and apparatus can be classified on the basis of following:

1. **The physical state and**
2. **Thermal stability or maximum permissible temperature rise**

(1) Classification on the basis of physical state:

(a) Solid insulating materials

Commonly used solid insulating materials are:

- Mica
- Ceramics
- Glass
- Rubber
- Asbestos
- Porcelain
- Fibrous
- Plastic
- Silk
- Wood
- Epoxy resins

(b) Liquid insulating materials

Commonly used liquid insulating materials are:

- Varnish
- Transformer oil
- Silicone oils
- Cable oil
- Synthetic liquids

(c) Gaseous insulating materials

Commonly used Gaseous insulating materials are:

- Air
- Sulphur
- Hexafluoride
- SF6 gas
- Nitrogen
- Freon
- Halogens
- Hydrogen

(2) Classification on the basis of thermal stability or maximum permissible temperature rise:

Indian standards (IS: 271) has specified the temperature ranges for different insulating materials used in Electrical machines and apparatus is as follows:

(i) Class Y insulation

Maximum working Temperature: 90° C

Example of class Y insulation: Cotton, Paper, Silk, PVC and Materials which neither impregnated nor immersed in oil.

(ii) Class A insulation

Maximum working Temperature: 105° C

Example of class A insulation: Cotton, Paper and Silk -when impregnated with natural resins or immersed in a liquid dielectric (oil) mainly used in electrical machines.

(iii) Class E insulation

Maximum working Temperature: 120° C

This class contains enamelled wire insulations on a base of
Polyvinyl formal, Polyurethane and epoxy resins, Mouldings, Powder plastics.

(iv) Class B insulation

Maximum working Temperature: 130° C

This class includes inorganic materials such as Mica, Fiberglass, Asbestos- which is impregnated with varnish and other compounds.

(v) Class F insulation

Maximum working Temperature: 155° C

This class includes Mica, Polyester, Epoxide varnishes and Varnishes with a high heat resistance as compared with class B materials.

(vi) Class H insulation

Maximum working Temperature: 180° C.

This class includes composite materials of Mica, Fiber glass and Asbestos- Which bases impregnated with silicone rubber. These materials are mainly used in dry type transformer.

(vii) Class C insulation

Maximum working Temperature: Above 180° C

This class includes Mica, Glass, Teflon, Quartz, Ceramics.

Applications of Insulating Material

The applications of insulating material are

- Cable and transmission lines
- Electronic systems
- Power systems
- Domestic portable appliances
- Electrical cable insulating tape
- Personal protective equipment
- Electrical rubber mats

A. Solid Inorganic Insulator: 1. Glass Insulator

Glass insulators are often used to protect electrical wires and prevent them from interacting with each other. It is usually found in **transmission towers, distribution poles, and telephone poles**.

Preparation

At high temperature, the glass insulators are designed or manufactured by mixing the different types of materials, including quartz and lime powder, and then cools in the mold.

Properties

The properties of the glass insulator are

- **Dielectric Strength:** The approximate value of dielectric strength is 140 kV/cm.
- **Compressive Strength:** The approximate value of compressive strength is 10,000 Kg/cm^2.
- **Tensile Strength:** The approximate value of tensile strength is 35,000 Kg/cm^2.

Glass insulators possess low coefficient of thermal expansion, high cracking resistance, and high electrical resistance. Annealed tough glass is used for the insulating purpose. Glass insulator has numbers of advantages over conventional porcelain insulator.

Advantages of Glass Insulator

1. It has a very high dielectric strength compared to porcelain.
2. Its resistivity is also very high.
3. It has a low coefficient of thermal expansion.
4. It has a higher tensile strength compared to porcelain insulator.
5. As it is transparent in nature the is not heated up in sunlight as porcelain.
6. The impurities and air bubbles can be easily detected inside the glass insulator body because of its transparency.
7. Glass has a very long service life because the mechanical and electrical properties of glass do not be affected by aging.
8. After all, glass is cheaper than porcelain.

Disadvantages of Glass Insulator

1. Moisture can easily be condensed on the glass surface and hence air dust will be deposited on the wed glass surface which will provide a path to the leakage current of the system.
2. For higher voltage glass cannot be cast in irregular shapes since due to irregular cooling internal strains are caused.

Applications

Nowadays **glass insulators** have become popular in transmission and distribution systems.

A. Solid Inorganic Insulator: 2. Ceramic Products

Ex: Porcelain Insulator Preparation

- Porcelain is the most commonly used material for overhead insulators in the present day. The porcelain is aluminum silicate.
- The aluminum silicate is mixed with plastic kaolin, feldspar, and quartz to obtain final hard and glazed **porcelain insulator** material. Thus, the surface of the insulator should be glazed enough so that water should not be traced on it.
- The porcelain can also be called as **ceramic.**

Properties

The properties of the porcelain insulator are

- **Dielectric Strength:** The approximate value of dielectric strength is 60 kV/cm.
- **Compressive Strength:** The approximate value of compressive strength is 70,000 Kg/cm².
- **Tensile Strength:** The approximate value of tensile strength is 500 Kg/cm².
- Porcelain also should be free from porosity since porosity is the main cause of deterioration of its dielectric property. It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

Advantages

The advantages of the porcelain insulator are

- Compared to glass insulator the mechanical strength of porcelain insulator is very high
- Leakage current is low
- It is less affected by temperature
- Long life
- Easy to maintain
- Highly Flexible
- Highly reliable
-

Disadvantages

The weak in tension and poor shock resistance is the disadvantages of a porcelain insulator.

Applications

The applications of this insulator are distribution and transmission lines, isolators, transformer bushings, fuse units, plugs, and sockets.

B. Solid Organic Insulator: Epoxy Resins

Ex: Resins (polymers)

Resins are-organic substances with a very high molecular weight. They are available in nature as well as artificially made. For an electrical insulating purpose, the natural resins these days have been replaced by synthetic resins. Synthetic resins are synthetic polymers sometimes called plastics and form an important group of insulating materials.

Resins can be classified on the basis of their behavior under heat, as *thermoplastic resins* and *thermosetting resins*.

The different resins are

- Natural resins
- Polyethylene, Polystyrene, Polyvinyl chloride (P.V.C)
- The Acrylic Resins (Polymethyl methacrylate)
- Polytetrafluoroethylene (Teflon), Polyamide Resins (Nylons)

- Resins derived from Cellulose
- Polyester Resins
- **Epoxy Resins**
- Phenolic Resins
- Silicon Resins

Epoxy Resin Preparation

Epoxy resins belong to the group of **thermosetting** insulating materials. Typical epoxy resins are obtained from the alkaline condensation of epichlorohydrin with dioxydiphenyl propane. Such polymers contain the reactive epoxy group. The commercial epoxy resins include Araldite, Debeckote, Epikot, etc.

Properties

- They possess excellent electrical and mechanical properties.
- Dielectric constant and loss tangents of such materials are 2.5-3.8 and 0.003-0.03, respectively, a typical value of resistivity being 10^{13}ohm-cm.

Advantages

The advantages of the polymer insulator are

- Compare to porcelain and glass insulator the polymer insulator is very lightweight
- Installation cost is low
- Tensile strength is higher than porcelain
- Better performance

Disadvantages

The disadvantage of the polymer insulator is if there is any unwanted gap between weather shed and core their moisture may enter.

Applications

- They are ideally suitable for casting of insulators, bushings etc for high voltages.
- They are also used to produce laminated and insulating varnishes.
- Epoxy resins are surely superior to all other plastics and resins. There is hardly any industry in which these resins are not used. They find applications in electrical and electronic devices, in space satellites, in supersonic aircraft, in oil wells, stained glass window, on roads and bridges and in computers.
- In switchgear, they are fully incorporated in the 5-30 kV range. In bushings, they are used above 15 kV. They are also used in transformers and busbars.

B. Liquid Insulator: Transformer Oil

Transformer oil is used in oil-filled electrical power transformers to insulate, stop arcing and corona discharge, and to dissipate the heat of the transformer (i.e. act as a coolant).

- **Transformer oil** (also known as insulating oil) is a special type of oil which has excellent electrical insulating properties and is stable at high temperatures.

- Transformer oil is also used to preserve the transformer's core and windings – as these are fully immersed inside the oil.
- Another important property of the insulating oil is its ability to prevent oxidation of the cellulose-made paper insulation. The transformer oil acts as a barrier between the atmospheric oxygen and the cellulose – avoiding direct contact and hence minimizing oxidation.
- The level of transformer oil is typically measured using a MOG (Magnetic Oil level Guage).

Production of Transformer Oil

- Transformer oil is normally obtained by fractional distillation and followed through crude petroleum.
- Transformer oil is hydrocarbon product, mainly oil contains napthanic, parrafinic and aromatics.
- The crude oil which is burried from earth crust subjected in to the following sequence of operations. Distillation-Acid treatment-Neutralization-Water wash-Hot air blowing.
- After the hot filtration operation, transformer oil is ready for filling the transformers.

Transformer Oil Types

There are two main **types of transformer oil** used in transformers

1. Paraffin based transformer oil
2. Naphtha based transformer oil

- Naphtha oil is more easily oxidized than paraffin oil. But the product of oxidation – i.e. sludge – in the naphtha oil is more soluble than the sludge from the paraffin oil. Thus sludge of naphtha-based oil is not precipitated in the bottom of the transformer. Hence it does not obstruct convection circulation of the oil, means it does not disturb the transformer cooling system.
- Although Paraffin oil has a lower oxidation rate than Naphtha oil, the oxidation product (sludge) is insoluble and precipitated at the bottom of the tank. This sludge acts as an obstruction to the transformer cooling system.
- Another problem with paraffin-based oil that the dissolved waxes inside of it can lead to a high pour point. Although this is not an issue in warmer climate conditions (such as India).

Despite the disadvantages mentioned above, paraffin-based oil is still commonly used in many countries (such as India) due to its high availability.

Transformer oil requirements

- Chemically stable to ensure minimum oxidation at higher operating temperatures.
- Low water Content to keep its dielectric strength
- High specific heat
- High thermal conductivity

- Low Density
- Non Toxic / Non PCB to avoid pollution problems.
- Good Arc quenching properties
- Simple to produce and cost is reasonable

Functions of Transformer Oil

To provide dielectric strength of the transformer insulation system.

- To provide efficient cooling.
- To protect the transformer core and coil assembly from chemical attack.
- To prevent the build up of sludge in the transformer.

Generally transformer oil is also known as insulating oil is oil that remains durable even at high temperature. Transformer oil does two major functions that is, it is liquid insulation in electric power transformer and secondly it consumes heat generated by transformer and serves as coolants.

Transformer Oil Properties

Some specific properties of insulating oil should be considered to determine the serviceability of the oil.

The properties (or parameters) of transformer oil are:

1. Electrical properties: Dielectric strength, specific resistance, dielectric dissipation factor.
2. Chemical properties: Water content, acidity, sludge content.
3. Physical properties: Interfacial tension, viscosity, flash point, pour point.

1. Electrical Properties of Transformer Oil:

a. Dielectric Strength of Transformer Oil

- The **dielectric strength of transformer oil** is also known as the breakdown voltage (BDV) of transformer oil. Breakdown voltage is measured by observing at what voltage, sparking strands between two electrodes immersed in the oil, separated by a specific gap.
- A low value of BDV indicates presence of moisture content and conducting substances in the oil. Minimum **breakdown voltage of transformer oil** or **dielectric strength of transformer oil** at which this oil can safely be used in transformer, is considered as 30 KV.

b. Specific Resistance of Transformer Oil

- The Resistivity of the insulating oil must be high at room temperature and also it should have good value at high temperature as well.
- That is why specific resistance or resistivity of transformer oil should get measured at 27^{o}C as well as 90^{o}C. Minimum standard specific resistance of transformer oil at 90^{o}C is 35×10^{12} ohm–cm and at 27^{o}C it is 1500×10^{12} ohm–cm.

c. Dielectric Dissipation Factor of Tan Delta of Transformer Oil

- Dielectric dissipation factor is also known as loss factor or **tan delta of transformer oil**. If the loss angle is small, then the resistive component of the current I_R is small which indicates a high resistive property of the insulating material. High resistive insulation is a good insulator. Hence it is desirable to have loss angle as small as possible. So we should try to keep the value of tanδ as small as possible. The high value of this tanδ is an indication of the presence of contaminants in transformer oil.
- Hence there is a clear relationship between tanδ and resistivity of insulating oil. If the resistivity of the insulating oil gets decreased, the value of tan-delta increases

and vice verse. So both resistivity test and **tan delta test of transformer oil** are generally not required for the same piece of the insulator or insulating oil.

- In one sentence it can be said that tanδ is a measure of the imperfection of dielectric nature of insulation materials like oil.

2. Chemical properties of Transformer Oil:

a. Water Content in Transformer Oil

- Moisture or **water content in transformer oil** is highly undesirable as it affects the dielectric properties of the oil adversely.
- The water content in oil also affects the paper insulation of the core and winding of a transformer. Paper is highly hygroscopic. Paper absorbs the maximum amount of water from oil which affects paper insulation property as well as reduced its life. But in a loaded transformer, oil becomes hotter, hence the solubility of water in oil increases.
- As a result, the paper releases water and increase the **water content in transformer oil**. Thus the temperature of the oil at the time of taking a sample for the test is critical. During oxidation, acids get formed in the oil the acids give rise to the solubility of water in the oil. Acid coupled with water further decompose the oil forming more acid and water. This rate of degradation of oil increases. We measure the water content in oil as ppm (parts per million unit).
- The water content in oil is allowed upto 50 ppm as recommended by IS–335(1993). The accurate measurement of water content at such low levels requires very sophisticated instrument like Coulometric Karl Fisher Titrator.

b. Acidity of Transformer Oil

- Acidic transformer oil is a harmful property.
- If oil becomes acidic, the water content in the oil becomes more soluble in the oil. The acidity of oil deteriorates the insulation property of paper insulation of winding.
- Acidity accelerates the oxidation process in the oil. Acid also includes rusting of iron in the presence of moisture.

3. Physical Properties of Transformer Oil

a. Inter Facial Tension of Transformer Oil

- Interfacial tension between the water and oil interface is the way to measure the attractive molecular force between water and oil.
- Interfacial tension is exactly useful for determining the presence of polar contaminants and oil decay products.
- Good new oil generally exhibits high interfacial tension. Oil oxidation contaminants lower the IFT.

b. Flash Point of Transformer Oil

- **Flash point of transformer oil** is the temperature at which oil gives enough vapors to produce a flammable mixture with air. This mixture gives momentary flash on the application of flame under standard condition.
- Flashpoint is important because it specifies the chances of fire hazard in the transformer. So it is desirable to have a very high **flash point of transformer oil**. In general it is more than $140^{o}(>10^{o})$.

c. Pour Point of Transformer Oil

- It is the minimum temperature at which oil starts to flow under standard test condition. Pour point of transformer oil is a valuable property mainly at the places where the climate is icy.
- If the oil temperature falls below the pour point, transformer oil stops convection flowing and obstruct cooling in a transformer. Paraffin-based oil has a higher value

of pour point, compared to Naphtha based oil, but in India like country, it does not affect the use of Paraffin oil due to its warm climate condition.

- Pour Point of transformer oil mainly depends upon wax content in the oil. As Paraffin-based oil has more wax content, it has higher pour point.

d. Viscosity of Transformer Oil

- The **viscosity of transformer oil** can be said that viscosity is the resistance of flow, in normal condition. Resistance to flow of transformer oil means obstruction of convection circulation of oil inside the transformer.
- Good oil should have a low viscosity so that it offers less resistance to the conventional flow of oil thereby not affecting the cooling of a transformer.
- Low **viscosity of transformer oil** is essential, but it is equally important that the viscosity of oil should increase as less as possible with a decrease in temperature. Every liquid becomes more viscous if the temperature decreases.

C. Gas Insulator: SF_6

Introduction

- Sulphur hexafluoride is an inorganic gas made up of sulphur and fluorine.
- Sulphur hexafluoride is one of the most stable gases known.
- Sulphur hexafluoride is a very dense gas so it will mainly reside in the lowest layers of air. Exposure will be primarily occupational.
- Sulphur hexafluoride is a weaker eluent than carbon dioxide and is difficult to obtain in adequate purity.
- It provides high dielectric strength and excellent arc-quenching properties.
- The high heat absorbing ability makes sulphur hexafluoride a strong greenhouse gas with a CO_2 equivalent contribution to the global warming potential.

Manufacturing of SF_6 Gas

- SF6 gas is commercially manufactured by the reaction of fluorine (obtained by electrolysis) with sulfur.

$$S + 3F_2 = SF_6 + 262\ KCal$$

- During process of producing of this gas, other byproducts like SF_4, SF_2, S_2F_2, S_2F_{10} are also produced in small percentages. Not only these byproduct, impurities like air, moisture, and CO_2 are also present in the gas, during production. All these byproducts and impurities are filtered at different stages of purification to get the pure and refined final product.

Properties

SF_6 – an excellent insulating and quenching gas

and it is

- Colourless and odourless
- 5 times heavier than air
- Temperature-resistant up to 500 °C
- Chemically stable
- Non-toxic
- Excellent dielectric properties
- Non-inflammable
- Outstanding arc quenching properties

Applications

- **Indispensable in energy transmission and distribution**

  Because of its dielelectric strength and excellent insulating properties, SF_6 has been used as an insulating gas for medium and high voltage components for many years. Its excellent arc quenching properties (100 times faster than air) has made it suitable as a proven medium in encapsulated medium and high voltage switchgear for decades. Thus, commonly used in electrical switchgear, transformers and substations as an electrical insulation, arc quenching and cooling medium

- **Use in other industry sectors**
  - Moreover, SF_6 gas is also used in other industries such as semi-conductor industry, in display and micro-technology where it mainly serves as etching gas for the production of ultra-fine structures, the so-called "wafers".
  - In medical technology sulphur hexafluoride is for example used for ultrasonic testing and in ophthalmology. SF_6 is also used in X-ray equipment, radar systems, particle accelerators and electron microscopes.