UNIT – III WEAR AND CORROSION AND THEIR PREVENTION

WEAR

Wear is one of several processes which occur when the surface of engineering components is loaded together and are subjected to sliding and/or rolling motion. Due to utilization and equipment, the reduction takes place in the dimension of parts slowly and continuously as the change in shape and surface finishing is known as Wear. Wear is a progressive loss of substance from the surface of a solid body caused by mechanical action. Manly five principle of wear are there; Adhesive, Abrasive, third body, Corrosive and Surface fatigue and it soon became possible to work out their mechanisms and express the amount of wear in quantitative terms.

WEAR MECHANISMS

1. **Adhesive Wear:**

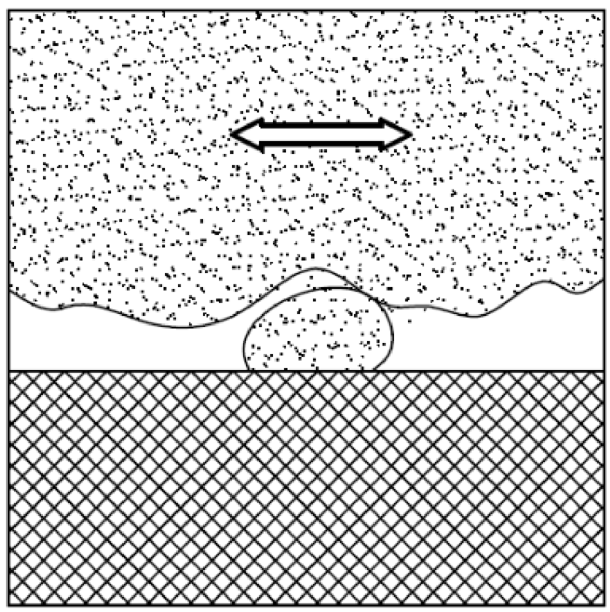


Fig. 1: Adhesive wear

This is the only universal form of wear, and a sliding system is also the most important. It arises from the fact that during sliding regions of the adhesive bonding called junctions from between the sliding surface. If one of these junctions does not back along its original interface, then a chunk from one of these sliding surfaces will have been transferred to the other surface. It means adhesive wear occurs when the atomic force occurring between the materials on two surfaces under relative load are stronger than the inherent material properties of either surface. For example, when there is relative motion between two or more surfaces bonding of asperities occurs. Continued motion of the surface required breaking the bond junction. Each time a bond junction is broken, a wear particle is created usually from the weaker material (Fig-1) In this way an adhesive wear particle will have been formed. Initially adhering to the other surface adhesive particle soon come off loose and can disappear from the sliding system. The volume of adhesive wear is governed by the equation V=kLx/3p, where V is the total volume of adhesive wear, k is a non- dimension constant called the wear coefficient, x is the total distance of sliding and p is the indentation hardness of the surface expressed as a stress. A very great reduction in wear by factors of up to million can be produced in metallic sliding systems by using a good lubricant. Also, there is a great advantage in making unlubricated sliding system nonmetallic and well lubricated system metallic. Adhesive wear caused two type of failure, one being aware-out mode which occurs after long periods of sliding because too much material has been removed and a seizure mode which occurs in system which generate wear particles larger than the clearance, thus producing jamming. Since many material combinations give wear particles larger than 10 micrometers, it is dangerous to reduce the clearance of any sliding system below this value.

2. **Abrasive Wear:**

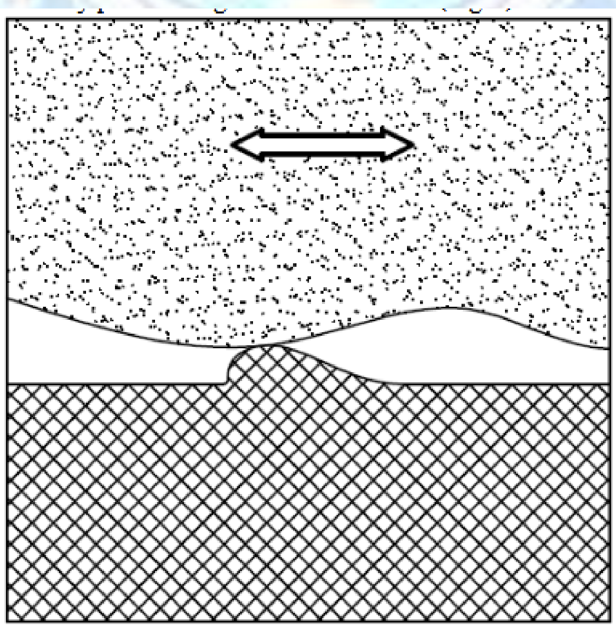


Fig. 2: Abrasive wears

This is the wear produced by a hard, sharp surface sliding against a softer one and digging out a groove. It means abrasive wear occurs between surfaces of the different relative hardens. In an abrasive wear mechanism, micro roughened regions and very small asperities on the harder surface locally plow through the softer surface (Fig-2). The results of Abrasive wear, softer material being removed from the track traced by the asperity during the motion of the harder surface. The abrasive agent may be one of the surfaces, such as a file, or it may be third component, and sand particles in a bearing abrading material from each surface. Abrasive wear, like adhesive wear, obeys the equation given above, typical values of k. It will be seen that abrasive wear coefficients are large compared to adhesive wear coefficients. Thus, the introduction of abrasive particles into sliding system can greatly increase the wear rate, so in automobile air and oil filter are used.

3. **Third Body:**

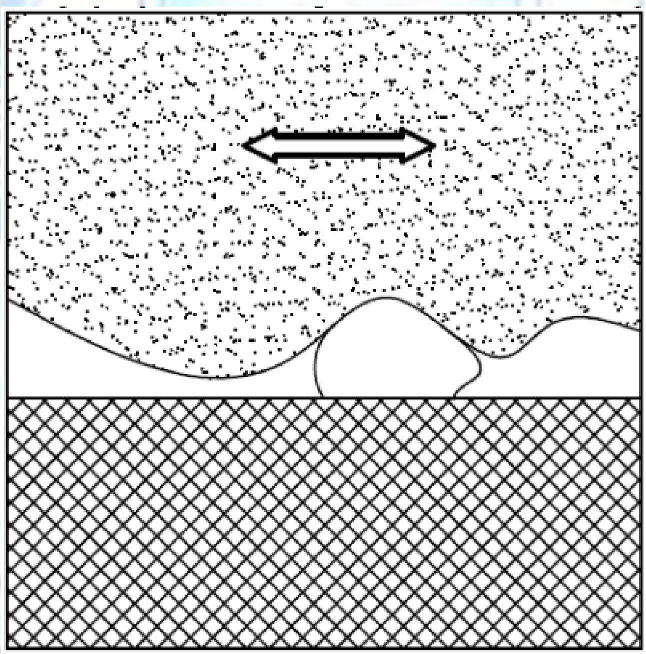


Fig. 3: Third body wear

Third body wear is a one type of abrasive wear that occurs when hard particles become embedded in a soft surface (Fig-3). Generally metallic or bone particles are embedded in a polyethylene bearing surface as third body particles. The particles acts are much like the asperity of a hard material in abrasive wear, removing material in its path. Hard third body particles like bone cement can produce damage to both the polyethylene articulating surface and the metallic alloy femoral bearing counter face. The extent of abrasive wear of polyethylene, metallic and ceramics has been shown to be a function of the surface roughness of the metallic or ceramic counter face and the presence or absence of hard third body particles. In one vitro hip simulator study, simulation of roughened femoral head increased the amount of wear damage to the polyethylene even in an elevated cross-linked polyethylene. In other studies, isolated scratches dramatically increased the wear rate than generalized roughness of the metallic counter face and could also change the wear performance ranking of various polyethylene formulations. Thus, the magnitude of the effect of surface roughness of the metallic counter face on overall wear remains controversial.

4. Corrosive Wear:

This form of wear a raised when a sliding surface is in corrosive environment and the sliding action continually removes the protective corrosion product; it means Corrosive wear is an indirect wear mechanism. Thus, exposing the fresh surface to further corrosive attack. Corrosive wear can be considered as an accelerating mechanism for corrosion itself, because the motion of an articulation can removes corrosive products and the protective passive layer sooner than interfaces with no relative motion. No satisfactory quantitative expression of corrosive wear yet exists but when analyzing it in terms of the above equation; k values are obtained ranging all the way from less than 10^{-5} for surface in a gently corrosive environment to above 10^{-2} for surface under severe corrosive attack.

5. Surface Fatigue Wear:

This is the wear that occurs as result of the formation and growth of cracks. It means Fatigue wear occurs when surface and subsurface cyclic shear stresses or strains in the softer materials of an articulation exceed the fatigue limit for that material. Because polyethylene is the weaker of the two materials in a bearing couple, fatigue wear damage to the polyethylene component dominates. Under these repeated or cyclic loading conditions, subsurface delaminating and cracking can occur, eventually leading to the release of polyethylene particles (Fig-4).

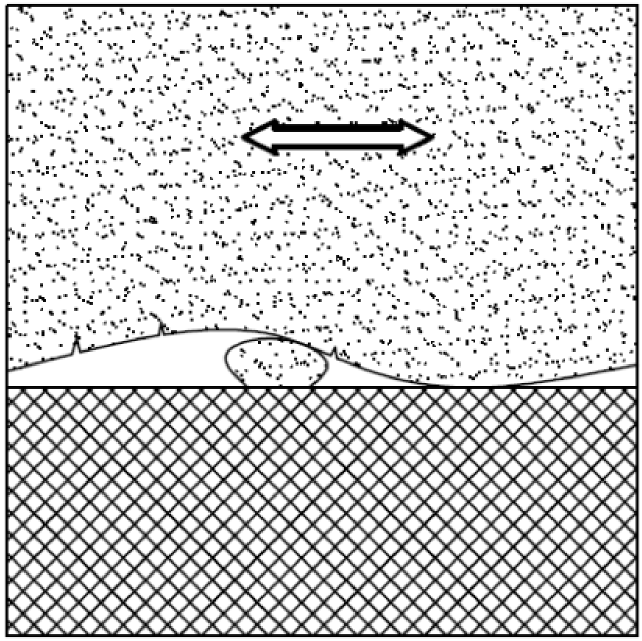


Fig. 4: Surface fatigue wear

Fatigue damage can range from very small areas of pitting, so not apparent on visual inspection to macroscopic pits several millimeters in diameter to large areas of delaminating that can encompass an entire tibial plateau. It is the main form of rolling devices like ball bearing, wheels on rails and gears. During continued rolling, a crack forms at or just below the surface and gradually grows until a largest particle is lifted right out of the surface. As per our above discussion, k value is different for different metal.

CAUSES OF WEAR

- Lack of Lubrication

- Overload

- Misalignments

- Friction between rubbing surfaces

- Faulty design

- Insufficient lubrication

- Improper lubrication

- Bad workmanship

- Rough finish on surface

- Insufficient clearance between surfaces

- Contest with dust/metal particles

- Effect of most air, water and chemicals

- Effect of temperature

- Improper tools used

EFFECTS OF WEAR

Many effects are generated when wear is doing like Noisy operation: Due to the wear, clearance of different mechanical parts is increasing and so pair of mating parts strikes against one-another, thus striking of various parts produces continuous noise. Low quality work: If there is increased clearance, the rigidity of machines reduces, and it is not utilized at full capacity and finally the quality of the product is reduced. Lowered efficiency: Due to the more clearance standards of machine are reduce and its capacity are also reduce. When using such machines, the efficiency of this machine is reduced. Vibration: Due to the wear and tear, the clearance adjusted is changing, which is producing vibration of machine and thus at this condition machine are not properly work and it's produced poor quality of work. Misalignment: Due to the wear, clearance of the bushing and shaft, ball bearing and roller bearing are increased, so position of shaft is changed. It means shafts are not rotated properly; this is known as misalignment. If such a machine is used further, then due to its vibration caused by change of alignment may lead to the failure of machine and its foundation. Overheating: Generally, temperature can be bare by touching the machine. If the temperature is higher than that it can be said to be an overheating machine. Due to overheating the parts are become loses their strength and the machine becomes faulty due to which it stops functioning. Overheating may result in the change of metallic structure of the parts. Leakage development: Due to the vibration caused by the wear of the parts, nut-bolts of coupling and flange loosening, thus leakage of oil have occurred. Leakage is affected in producing corrosion, low efficiency of machine and low safety in operation.

WEAR REDUCTION METHOD

We know that wearing only reduced it can't be prevented. We can reduce the wear, but wear elimination is not possible. Many techniques are developed for reducing wear, which is described below.

1. Prevention of Overloading:

Overloading is a big parameter for generating a wear in part; due to the overloading lubricants oil film between the parts will burst away and create an extra force on the wearing surface therefore overloading should be avoided.

2. Maintain Proper Clearance:

If the clearance between the surfaces is less, lubrication oil film cannot be provided the wearing surface and so metal to metal contact are developed. If more clearance is provided between the surfaces the motion is lost. Due to lack of lubrication parts the surface wore out very rapidly, produced noise and generated the vibration on the machine.

3. Improper Lubrication:

Improper lubrication means correct grade oil, correct lubrication method used, correct place selection and correct lubrication volume. Lubrication provided a film of lubricants in the clearance between the mating surface, and it increases the smoothness of the rubbing surface and prevents the metal-to-metal contact of the mating surface.

4. Improving the Surface Finishing:

When part is pass in machining process then different type of straight or circular lays depth is generated, which is cannot be seen by naked eyes. By Improper surface these lays are reducing and friction force not generating more. Due to the good surface a line contact is obtained instead of point contact, which is an advantage in processes.

5. High Surface Hardness:

Wear of hard surface is taking place in comparison to soft surface. Shaft, bearing, guide way is heat treated to increase their surface hardness than its wear is reduced.

6. Proper Surface Treatment:

Mechanical wear can be reduced by a hard layer of some metal, like Chromium, Galvanic etc. After producing a hard layer of chromium on the surface, if it can be machining to get desired dimensions and surface finish. Hence it can be said that hard layer can be provided on the surface of the wear resistant metal, the wear of the part can be reduced.

7. Protection of Surface Against the Ingress of Dirt, Dust and Metal Particles:

If dirt, dust and metal particle are ingresses into the bearing that they are crushed further. If such particles are harder than the part surface, so part surface will be worn and it's damaged.

8. Proper Atmosphere:

In the atmosphere dirt, dust moisture, poisonous chemical vapor and dust of product itself are present and it is affected machining functions and reduced of their service life. Some other methods are also used for reducing a wear like proper maintain at right time, the adjustments of varied clearance at time to time, proper planning, implementation of prevention maintenance, controlling the preventive maintenance activity properly, selection of suitable material for the part, reducing the sliding pairs with the replacement by rolling pairs, used automatic maintenance facility.

INDUSTRIAL LUBRICANT

Industrial lubricants are substances that are used to reduce friction and provide lubrication between moving parts in machinery and equipment. They are crucial for ensuring the smooth operation, longevity, and reliability of various industrial applications. In this blog post, we will delve into the different types of industrial lubricants, discuss considerations for choosing the right lubricant, and provide guidelines for proper handling and storage practices.

TYPES OF INDUSTRIAL LUBRICANTS:

1. Grease:

Grease is a semisolid lubricant that consists of a base oil thickened with a soap-like material called a thickener. It offers excellent adhesion, sealing properties, and resistance to water washout. Grease is commonly used in applications with slow or intermittent movement, high loads, and extreme temperatures.

Types of Industrial Grease:

- **Lithium Grease:** Lithium grease is a general-purpose grease widely used in industrial applications. It has excellent mechanical stability, good temperature resistance, and water resistance. It is suitable for various applications such as bearings, gears, and general lubrication.
- **Calcium Grease:** Calcium grease is another versatile grease used in industrial settings. It offers good water resistance and is often used in automotive applications, chassis points, and heavy machinery.
- **Silicone Grease:** Silicone grease is a non-melting, high-temperature grease with excellent resistance to oxidation and thermal stability. It is commonly used in applications involving high temperatures, electrical connectors, rubber parts, and plastic components.
- **Polyurea Grease:** Polyurea grease is a synthetic grease that provides excellent high-temperature performance and long-term stability. It is commonly used in electric motor bearings, sealed-for-life bearings, and applications where there is a need for extended lubrication intervals.
- **Synthetic Grease:** Synthetic greases are manufactured using synthetic base oils and additives to provide enhanced performance characteristics. These greases are designed to offer improved temperature resistance, oxidation stability, and longer service life compared to conventional greases. They find applications in various industries, including automotive, aerospace, and heavy machinery.
- **PTFE Grease:** PTFE (polytetrafluoroethylene) grease contains a lubricating solid called PTFE, which provides excellent low friction and anti-wear properties. PTFE grease is often used in applications where there is a need for reduced friction, such as bearings, sliding mechanisms, and high-speed equipment.

2. Liquid Lubricants:

Liquid lubricants, commonly referred to as oils, are fluid lubricants that offer excellent lubrication properties. They are used in applications where continuous lubrication is required, such as circulating systems or machinery with complex parts. Liquid lubricants are available in various formulations, including mineral oils, synthetic oils, and vegetable-based oils. Mineral oils are derived from crude oil and are cost-effective, while synthetic oils are chemically engineered to offer superior performance, such as high-temperature stability and extended oil change intervals. Vegetable-based oils are environmentally friendly options that are biodegradable and less toxic.

Factors to Consider When Selecting Lubricants:

When selecting industrial lubricants, several factors should be considered to ensure optimal performance and compatibility with the application. Some key considerations include:

1. Oil Lubrication:

Oil lubrication is widely used in various industrial applications. It is essential for ensuring proper lubrication of bearings, which are critical components in machinery. Proper oil lubrication provides a protective film between the rolling elements and races of bearings, reducing friction and preventing premature wear.

2. Bearings and Oil :

When selecting oil for bearings, it's important to consider factors such as load, speed, temperature, and environmental conditions. Bearing manufacturers often provide guidelines specifying the recommended oil type and viscosity for their products. Adhering to these guidelines helps ensure optimal bearing performance and extended service life.

3. Oil Type:

Choosing the right oil type is crucial, as different oils have varying properties and performance characteristics. Some common oil types include mineral oils, synthetic oils, and biodegradable oils. Mineral oils are suitable for general-purpose applications, while synthetic oils offer enhanced performance in terms of oxidation resistance, thermal stability, and viscosity index. Biodegradable oils are preferred for environmentally sensitive applications.

4. Oil Viscosity:

The viscosity of an oil quantifies its ability to resist flow. It plays a significant role in determining the lubricant's ability to maintain a protective film and carry away heat. The appropriate viscosity grade is determined based on factors such as operating temperature, speed, load, and equipment manufacturer recommendations. Low-viscosity oils are used in high-speed applications, while high-viscosity oils are used in heavy-load or high-temperature applications.

5. Grease Lubrication:

Grease lubrication is widely used in applications where oil lubrication may not be feasible or effective. Grease provides better adhesion and sealing properties, making it suitable for applications with slow or intermittent movement, high loads, and extreme temperatures. It is commonly used in bearings, gears, and other components that require long-lasting lubrication.

6. Grease Thickening:

Grease contains a thickening agent that gives it its semisolid consistency. Different thickening agents, such as lithium, calcium, polyurea, and aluminium complex, are used to achieve specific performance characteristics. The choice of thickener depends on factors such as operating temperature, speed, load, and compatibility with the application.

7. The Need for Grease Specifications:

Different applications require greases with specific properties and certifications. It is important to consider industry standards and specifications when selecting grease. For example, food-grade greases are necessary for lubricating equipment in the food and beverage industry to ensure compliance with safety regulations.

8. Low Temperatures:

In cold environments, it is crucial to choose lubricants that can withstand low temperatures without solidifying or losing their lubricating properties. Special low-temperature greases or synthetic oils are often recommended to ensure smooth operation in frigid conditions.

9. High Temperatures:

High-temperature applications pose challenges for lubrication due to increased heat and potential oil breakdown. Selecting lubricants with high thermal stability and oxidation resistance is vital to prevent viscosity loss, deposits, and premature wear. Synthetic oils and greases formulated for high-temperature applications are commonly used in such conditions.

10. Effects of Water:

In applications where water or moisture is present, such as marine or outdoor equipment, it is crucial to choose lubricants with excellent water resistance. Water-resistant greases and oils help prevent rust, corrosion, and washing out of the lubricant, ensuring reliable performance and protection

Managing and Preserving Lubricants:

Proper handling and storage practices are essential to maintain the quality and performance of industrial lubricants. Some important guidelines include:

1. Industrial Oil Filtration:

Regular oil filtration is necessary to remove contaminants and extend the life of the lubricant. Filtration systems help remove particles, water, and other impurities that can degrade the lubricating properties of the oil. Implementing effective oil filtration practices promotes equipment reliability and reduces maintenance costs. Proper filtration helps maintain the cleanliness of the lubricant, ensuring optimal performance and preventing premature component wear.

2. Green Practices:

In today's environmentally conscious world, adopting green practices in lubricant handling and storage is crucial. This includes proper disposal of used lubricants according to local regulations and recycling containers whenever possible. Additionally, choosing biodegradable or eco-friendly lubricants can help minimize the environmental impact of industrial operations.

3. Storage Conditions:

Proper storage conditions are necessary to maintain the quality and effectiveness of lubricants. Lubricants should be stored in a clean, dry, and well-ventilated area, away from direct sunlight and extreme temperatures. It is important to prevent contamination by keeping lubricant containers sealed and avoiding contact with water, dirt, and dust. Additionally, lubricants should be stored in a way that ensures easy identification and proper rotation based on their expiration dates.

4. Contamination Prevention:

Contamination can severely affect the performance of lubricants. It is crucial to handle lubricant containers and dispensing equipment with clean and dry hands to avoid introducing contaminants. Using dedicated equipment, such as pumps and funnels, for transferring lubricants helps prevent cross-contamination. Additionally, keeping storage areas clean and using proper filtration systems during oil transfer and refilling processes reduces the risk of contaminants entering the lubrication system.

5. Inventory Management:

Implementing an effective inventory management system ensures that lubricants are properly tracked, stored, and replenished. This helps prevent stockouts and ensures that the right lubricant is available when needed. Regular inspections and audits of lubricant inventory can identify any issues, such as expired products or improper storage, and allow for corrective actions to be taken promptly.

Industrial lubricants are essential for maintaining the performance, efficiency, and durability of machinery and equipment in various industries. By understanding the different types of lubricants available and considering factors such as application requirements, temperature conditions, and compatibility, businesses can choose the most suitable lubricants for their specific needs. Proper handling, storage, and filtration practices further contribute to maximizing the lifespan and reliability of lubricants, reducing maintenance costs, and promoting environmentally responsible operations.

LIST OF LUBRICATORS USED IN MACHINES

Most used lubricators used in machineries and industries are as follows: 1. Screw Cap Lubricator 2. Tell-Tale Lubricator 3. Glass Bottle Lubricator 4. Wick Feed Lubricator 5. Ring Oil Lubricator 6. Splash Lubricator 7. Full Pressure Lubrication.

Lubricator is a device for applying a specific amount of lubricant to the engine shaft and machine components such as bearings, gears, and other engine parts such as trunk piston, gudgeon pin, connecting rod, etc. For simple machine parts, simple types of lubricators are used such as oil can, grease plug, grease gun, etc.

1. Screw Cap Lubricator (Grease Lubricator):

Figure 8.4 shows the screw cap lubricator. It has a lubricator body to hold grease. A knurled cap is screwed over the top portion of the lubrication body.

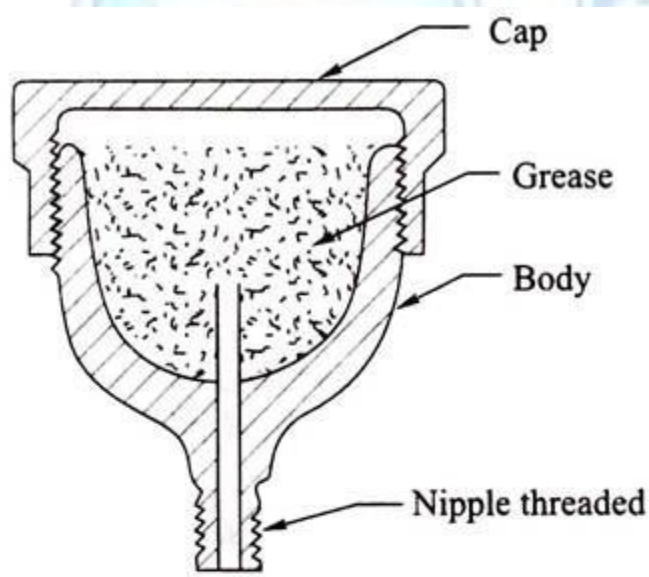


Fig. 8.4 Screw cap lubricator

The lower part of the body has a threaded nipple to be fitted with the bearing or machine parts to be lubricated. The operation of the lubricator is very simple. The grease is kept in the body. It can be operated manually by turning the knurled cap. The amount of grease is pushed in through the capillary to the engine parts to be lubricated. Such lubricators have been found in flour mills, agriculture equipment.

2. Tell-Tale Lubricator:

Figure 8.5 depicts a tell-tale lubricator. It is the improved version of the screw cap lubricator. The grease is kept in a container. It forces the grease by spring pressure exerted through a plunger attached with the knob. The flow of grease is accelerated with the help of a knob which moves the plunger downward pushing the grease through grub screw. The knob attached with the piston acts as a tell-tale which is visible from a distance and indicates the level of grease. One rotation of the knob supplies the grease to the surface to be lubricated.

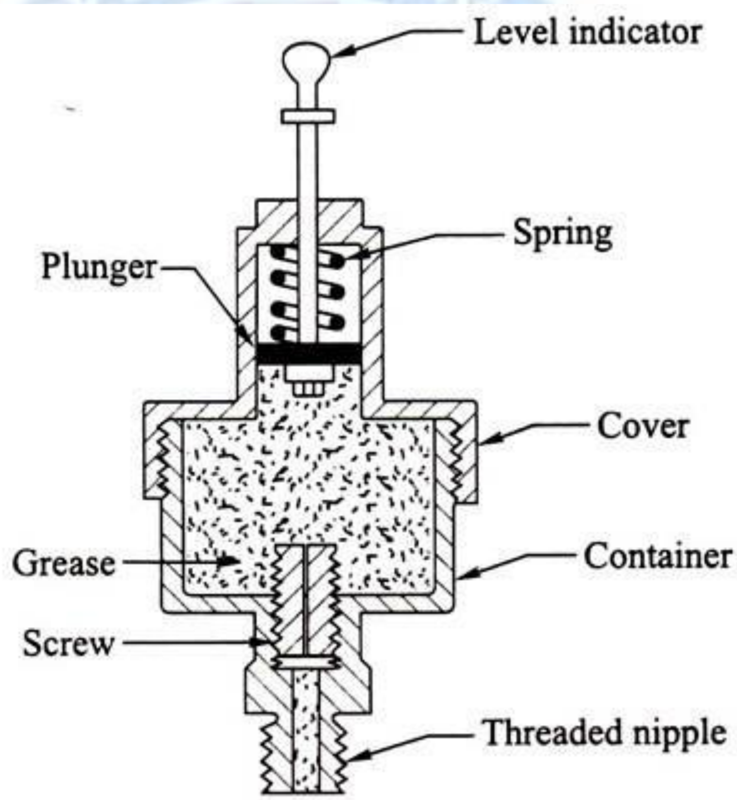


Fig. 8.5 Tell-tale lubricator

3. Glass Bottle Lubricator (Needle Lubricator):

Glass bottle lubricator is a bottle made of glass which holds the lubricating oil. The glass bottle is fitted with a tapered wooden cork which is also equipped with a loosely fitted steel needle. The bottle is fitted as shown in Fig. 8.6. The wooden fixture fitted with bottle is also fitted with bearing cap.

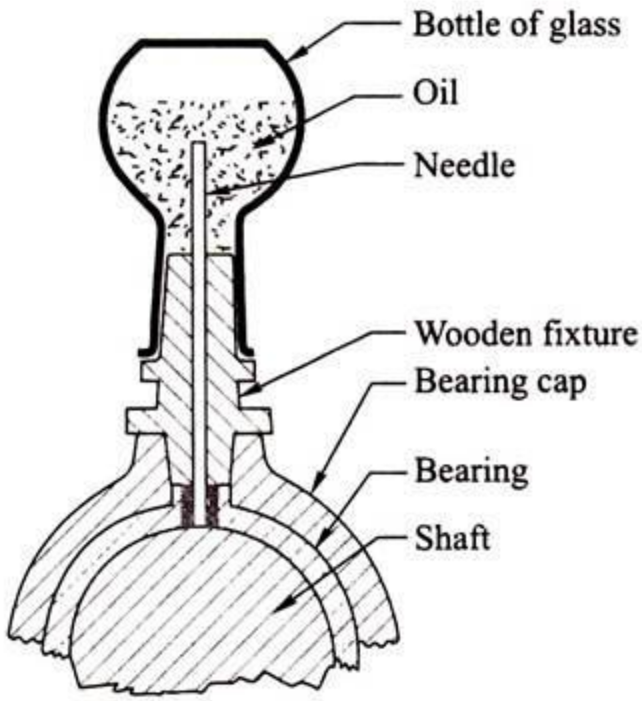


Fig. 8.6 Glass lubricator with needle

When the shaft rotates, the needle is well accelerated and due to vibration and jerks developed, the oil flows into the bearing by gravity.

4. Wick Feed Lubricator:

Figure 8.7 show the assembled drawing of wick feed lubricator. The working of this lubricator is based on the siphon principle. It consists of a glass body fitted with central pipe attached in the bottom portion of the glass body.

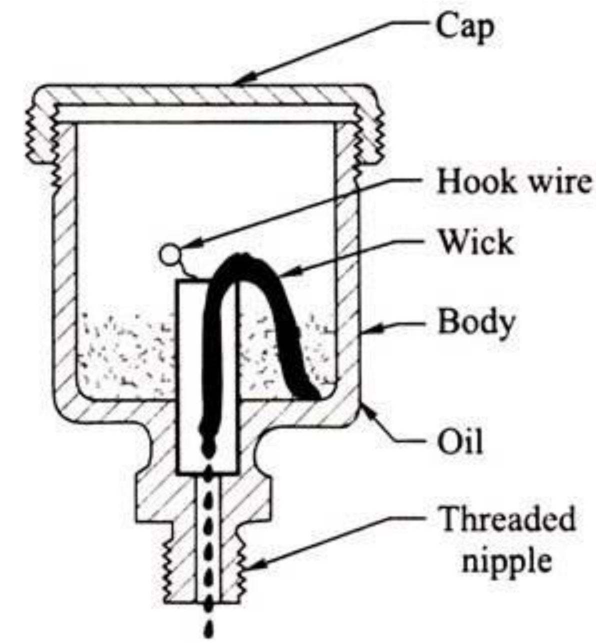


Fig. 8.7 Lubricator through wick

The lower portion of the body has the provision to fix the threaded nipple to the machine components and the machinery to be lubricated. The threaded nipple will have an oil hole through which the oil drops down. A cotton wick hangs about 40 mm below the oil level. The cotton wick gets soaked in the oil. The oil is dripped off by gravity and vibration caused by the motion of the machine components. The flow rate depends on the type and twist of the rope. A wire hook is provided to take out the wick when machine is in idle conditions. Wick feed lubricators are used for the lubrication of slides, guides, spindles, and plain bearings.

5. Ring Oil Lubricator:

Ring oil lubricator is shown in Fig. 8.8. It consists of an oil trough to keep sufficient oil in it. The trough acts as storage of oil and is placed below the shaft to be lubricated.

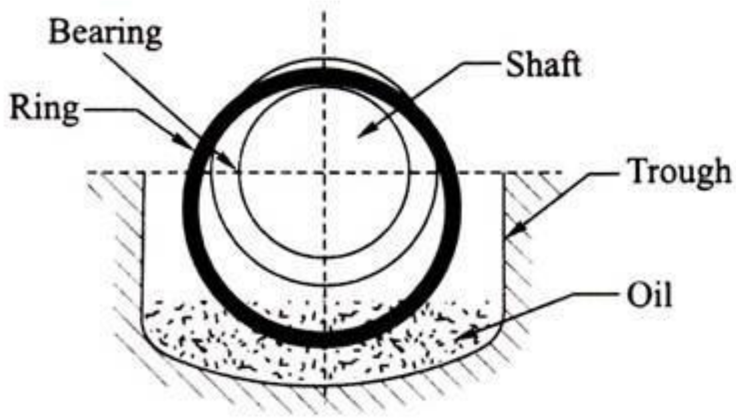


Fig. 8.8 Ring oil lubricator

A metallic ring hangs over the shaft and the bottom portion of the ring hangs in oil. When the journal rotates, the ring also rotates, and it carries oil from the oil bath and spreads the oil. The oil is placed on top of the bearing. The oil is further distributed to the bearing through the oil grooves. The excess oil spread drops down in the oil trough. The system is found suitable for slow-speed horizontal shaft. For high-speed engine shaft, the ring slips due to excess centrifugal force developed due to high rotation. In place of ring, steel chains can also be used. The sheet chains carry more lubricating oil.

6. Splash Lubricator:

The method is well known and generally used for the lubrication of internal combustion engine components. The closed crank case holds the lubricating oil up to such level that the crank pin dips into the oil. In each revolution of crank, the pin dips in the oil and splashes on the surface of cylinder liner, piston, dudgeon pin, piston rings, and crank shaft bearing. The excess splashed oil returns to the crank case. Figure 8.9 shows that splash lubrication system has been used for the lubrication of single cylinder internal combustion engine.

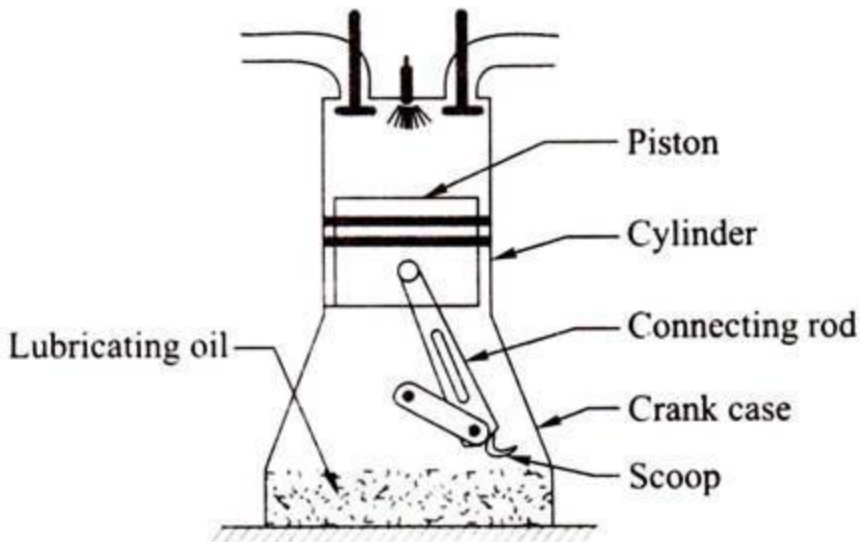


Fig. 8.9 Splash lubricator

A scoop is connected in the lower part of the big end of the connecting rod. When engine runs and the lower part of the big end comes down nearer to the oil level, a scoop attached with the big end dips in oil and splashes the oil from oil trough engine parts to be lubricated. It is the simplest and cheapest method of lubrication.

7. Full Pressure Lubrication:

Full pressure lubrication system, shown schematically in Fig. 8.10, is used for the lubrication of engine parts. Multi-cylinder IC engines have many moving parts and are required to be lubricated for its proper functioning. The engine lubrication system circulates oil from the crank case at the bottom and may be called wet sump lubrication. In this case, oil is forced through different parts under pressure by a pump.

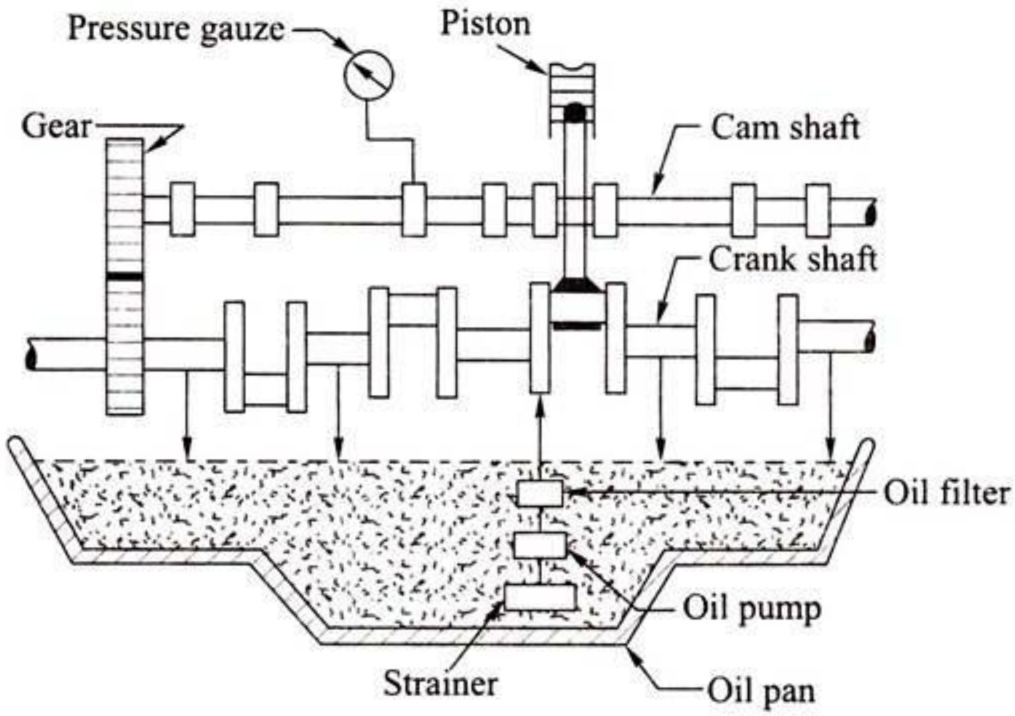


Fig. 8.10 Full pressure lubrication system

Oil enters the connecting rod bearing and crank shaft through drill passages. The system is capable of supplying oil to crank shaft bearing, cam shaft, valves, rocker arms, piston, piston rings, etc. Full pressure lubrication system is best suited for large multi-cylinder engines. After lubrication, excess oil returns to the oil sump and the process is repeated.

CORROSION

Corrosion is basically defined as a natural process that causes the transformation of pure metals into undesirable substances when they react with substances like water or air. This reaction causes damage and disintegration of the metal, starting from the portion of the metal exposed to the environment and spreading to the entire bulk of the metal. Corrosion is usually an undesirable phenomenon since it negatively affects the desirable properties of the metal. For example, iron is known to have good tensile strength and rigidity (especially alloyed with a few other elements). However, when subjected to rusting, iron objects become brittle, flaky, and structurally unsound. On the other hand, corrosion is a diffusion-controlled process, and it mostly occurs on exposed surfaces. Therefore, in some cases, attempts are made to reduce the activity of the exposed surface and increase a material's corrosion resistance. Processes such as passivation and chromate conversion are used for this purpose. However, some corrosion mechanisms are not always visible, and they are even less predictable. On the other hand, corrosion can be classified as an electrochemical process since it usually involves redox reactions between the metal and certain atmospheric agents such as water, oxygen, sulphur dioxide, etc.

Do All Metals Corrode?

Metals placed higher in the reactivity series, such as iron, zinc, etc., get corroded very easily, and metals placed lower in the reactivity series, like gold, platinum and palladium, do not corrode. The explanation lies in the fact that corrosion involves the oxidation of metals. As we go down, the reactivity series tendency to get oxidised is very low (oxidation potentials are very low). Interestingly, aluminium doesn't corrode, unlike other metals, even though it is reactive. This is because aluminium is covered by a layer of aluminium oxide already. This layer of aluminium oxide protects it from further corrosion.

Factors Affecting Corrosion

1. Exposure of the metals to air containing gases like CO_2, SO_2, SO_3 etc.

2. Exposure of metals to moisture, especially salt water (which increases the rate of corrosion).

3. Presence of impurities like salt (For example, NaCl).

4. Temperature: An increase in temperature increases corrosion.

5. Nature of the first layer of oxide formed: Some oxides like Al_2O_3 form an insoluble protecting layer that can prevent further corrosion. Others, like rust, easily crumble and expose the rest of the metal.

6. Presence of acid in the atmosphere: Acids can easily accelerate the process of corrosion.

Rate of Corrosion

The Deal–Grove model is often used to describe the formation of an oxide layer. This model helps in predicting and controlling oxide layer formation in a lot of diverse situations. Apart from this, the weight loss method is also used to measure corrosion. In this method, a clean, weighed piece of the metal or alloy is exposed to the corrosive environment for a certain duration. This is followed by a cleaning process that removes the corrosion products. The piece is then weighed to determine the loss of weight.

The rate of corrosion (R) is calculated as:

$$R = \frac{kW}{\rho A t}$$

Where,

k = constant,

W = weight loss of the metal in time t,

A = surface area of the metal exposed,

ρ is the density of the metal (in g/cm^3).

TYPES OF CORROSION

Some of the corrosion types include the following:

(i) Crevice Corrosion

Whenever there is a difference in ionic concentration between any two local areas of a metal, a localised form of corrosion known as crevice corrosion can occur. For instance, this form of corrosion mostly occurs in confined spaces (crevices). Examples of areas where crevice corrosion can occur are gaskets, the undersurface of washers, and bolt heads. All grades of aluminium alloys and stainless steels also undergo crevice corrosion. This is mainly because of the formation of a differential aeration cell that leads to the formation of corrosion inside the crevices.

(ii) Stress Corrosion Cracking

Stress corrosion cracking can be abbreviated to 'SCC' and refers to the cracking of the metal because of the corrosive environment and the tensile stress placed on the metal. It often occurs at high temperatures.

For example, stress corrosion cracking of austenitic stainless steel in chloride solution.

(iii) Intergranular Corrosion

Intergranular corrosion occurs due to the presence of impurities in the grain boundaries that separate the grain formed during the solidification of the metal alloy. It can also occur via the depletion or enrichment of the alloy at these grain boundaries.

For example, Aluminum-base alloys are affected by IGC.

(iv) Galvanic Corrosion

When there exists an electric contact between two metals that are electrochemically dissimilar and are in an electrolytic environment, galvanic corrosion can arise. It refers to the degradation of one of these metals at a joint or at a junction. A good example of this type of corrosion would be the degradation that occurs when copper, in a salt-water environment, encounters steel.

For example, when aluminium and carbon steel are connected and immersed in seawater, aluminium corrodes faster, and steel is protected.

(iv) Pitting Corrosion

Pitting Corrosion is very unpredictable and, therefore, is difficult to detect. It is considered one of the most dangerous types of corrosion. It occurs at a local point and proceeds with the formation of a corrosion cell surrounded by the normal metallic surface. Once this 'pit' is formed, it continues to grow and can take various shapes. The pit slowly penetrates metal from the surface in a vertical direction, eventually leading to structural failure if left unchecked.

For example, consider a droplet of water on a steel surface, pitting will initiate at the centre of the water droplet (anodic site).

(v) Uniform Corrosion

This is considered the most common form of corrosion wherein an attack on the surface of the metal is executed by the atmosphere. The extent of the corrosion is easily discernible. This type of corrosion has a relatively low impact on the performance of the material.

For example, a piece of zinc and steel immersed in diluted sulphuric acid would usually dissolve over its entire surface at a constant rate.

(vi) Hydrogen Grooving

This is a corrosion of the piping by grooves that are formed due to the interaction of a corrosive agent, corroded pipe constituents, and hydrogen gas bubbles. The bubbles usually remove the protective coating once it comes in contact with the material.

(vii) Metal Dusting

Metal dusting is a damaging form of corrosion that occurs when vulnerable materials are exposed to certain environments with high carbon activities, including synthesis gas. The corrosion results in the break-up of bulk metal to metal powder. Corrosion occurs as a graphite layer is deposited on the surface of the metals from carbon monoxide (CO) in the vapour phase. This graphite layer then goes on to form meta-stable M_3C species (where M is a metal) that usually move away from the metal surface. In some cases, no M_3C species may be observed. This means that the metal atoms have been directly transferred into the graphite layer.

(viii) Microbial Corrosion

Microbial corrosion, which is also known as microbiologically influenced corrosion (MIC), is a type of corrosion that is caused by microorganisms. The most common one is chemoautotrophs. Both metallic and non-metallic materials, either in the presence or absence of oxygen, can be affected by this corrosion.

(viii) High-temperature Corrosion

High-temperature corrosion, as the name suggests, is a type of corrosion of materials (mostly metals) due to heating. Chemical deterioration of metal can occur due to a hot atmosphere that contains gases such as oxygen, sulphur, or other compounds. These compounds are capable of oxidising the materials (metals in this case) easily. For example, materials used in car engines have to resist sustained periods at high temperatures, during which they can be affected by an atmosphere containing corrosive products of combustion.

Corrosion Examples, Reactions and Effects

Here are some typical examples of corrosion, as seen mostly in metals.

1. Copper Corrosion

When copper metal is exposed to the environment, it reacts with the oxygen in the atmosphere to form copper (I) oxide, which is red in colour.

$2Cu_{(s)} + \frac{1}{2} O_{2(g)} \rightarrow Cu_2O_{(s)}$

Cu_2O further gets oxidised to form CuO, which is black in colour.

$Cu_2O_{(s)} + \frac{1}{2} O_{2(g)} \rightarrow 2CuO_{(s)}$

This CuO reacts with CO_2, SO_3 and H_2O (present in the atmosphere to form $Cu_2(OH)_{2(s)}$ (Malachite), which is blue in colour and $Cu_4SO_4(OH)_{6(s)}$ (Brochantite), which is green in colour.

This is why we observe copper turning bluish-green in colour.

A typical example of this is the colour of the Statue of Liberty, which has the copper coating on it turning blue-green in colour.

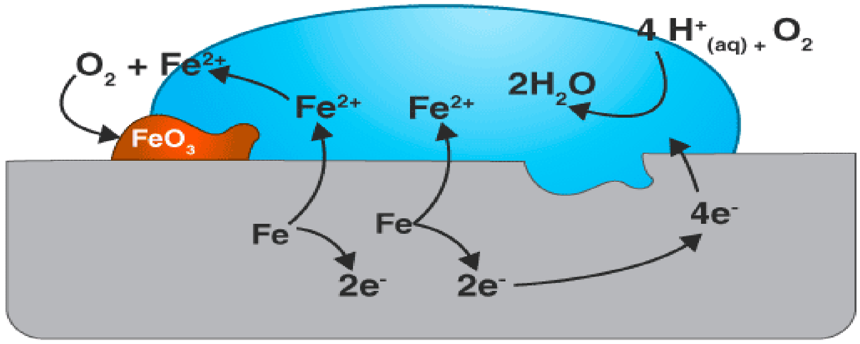
2. Silver Tarnishing

Silver reacts with sulphur and sulphur compounds in the air, giving silver sulphide (Ag_2S), which is black in colour. Exposed silver forms Ag_2S as it reacts with the $H_2S_{(g)}$ in the atmosphere, which is present due to certain industrial processes.

$2Ag_{(s)} + H_2S_{(g)} \rightarrow Ag_2S_{(s)} + H^{+}{}_{2}+(g)$

3. Corrosion of Iron (Rusting)

Rusting of iron, which is the most commonly seen example, happens when iron comes in contact with air or water. The reaction could be seen as a typical electrochemical cell reaction. Consider the diagram given below.



Here, metal iron loses electrons and gets converted to $Fe_{\{aq\}}^{2+}$ (this could be considered as the anode position). The electrons lost will move to the other side, where they combine with H^+ ions. H^+ ions are released either by H_2O or by H_2CO_3 present in the atmosphere (this could be considered as the cathode position).

$H_2O \rightleftharpoons H^+ + OH^-$

$H_2CO_3 \rightleftharpoons 2H^+ + CO_3^{2}$

The Hydrogen, thus formed by the reaction of H^+ and electrons, react with oxygen to form H_2O.

Anode reaction

$2Fe_{(s)} \rightarrow 2Fe^{2+} + 4e^-$;

Cathode reaction

$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l) E^o H^+/O_2/H_2/O = 1.23V$

Overall reaction

$2Fe_{(s)} + O_{2(g)} + 4H^+_{(aq)} \rightarrow 2Fe^{2+}_{(aq)} + 2H_2O_{(l)} E^o_{cell} = 1.67V$

The Fe^{2+} ions formed at the anode react with oxygen in the atmosphere, thereby getting oxidised to Fe^{3+} and forming Fe_2O_3, which comes out in the hydrated form as $Fe_2O_3.xH_2O$

$Fe^{2+} + 3O_2 \rightarrow 2Fe_2O_3$

$Fe_2O_3 + xH_2O \rightarrow Fe_2O_3.\ xH_2O$ (rust)

EFFECTS OF CORROSION

Corrosion can have a varying degree of effect on a lot of things. As such, it mainly causes waste of natural resources. Additionally, it can further cause hazardous situations such as building structures becoming weak and unstable, accidents caused by corroded parts as well as other unwanted failures, such as cracked pipelines, bridge collapsing, transport vehicle crashes or other catastrophes. It is, therefore, important to check and prevent corrosion at all costs.

PREVENTION OF CORROSION

Preventing corrosion is of utmost importance to avoid huge losses. Most of the structures that we see, and use are made out of metals. This includes bridges, automobiles, machinery, household goods like window grills, doors, railway lines, etc. While this is a concerning issue, several treatments are used to slow or prevent corrosion damage to metallic objects. This is especially done to those materials that are frequently exposed to the weather, saltwater, acids, or other hostile environments. Some of the popular methods to prevent corrosion include,

- Electroplating
- Galvanization
- Anodization
- Passivation
- Biofilm Coatings
- Anti-Corrosion Protective Coatings
- Painting and Greasing
- Use of Corrosion Inhibitor or Drying Agents
- Periodic Cleaning of Metal Surface

Electroplating

The main purpose of electroplating is to improve:

- Appearance
- Protection against corrosion
- Special surface properties
- Engineering or mechanical properties

In the process of electroplating the anode is connected to the positive terminal, and the cathode (metal to be plated) is connected to the negative terminal. Both are immersed in a solution that contains an electrolyte and then connected to an external supply of direct current. When DC power is applied, the anode is oxidized—its metal atoms dissolve in the electrolyte solution. These dissolved metal ions are reduced at the cathode and form a coating. The current through the circuit is adjusted so that the rate at which the anode is dissolved equals the rate at which the cathode is plated. Different metals can be coated using the electroplating process

Passivation

It involves applying an outer layer to a material to protect it from harmful reactions such as corrosion reactions. The layer may occur spontaneously in nature through a process called self-passivating, or it can be introduced to the material as a micro-coating. In this case, a light coat of material, for instance a metal oxide is used to form a shield against corrosion. In microelectronics, passivation is useful in the enhancement of silicon. The great practical significance of passivation is that it protects structural metals from rapid corrosion that occurs in fresh water, moist atmosphere and aggressive chemical mediums.

Biofilm

- A protective biofilm, which secretes a poly anionic chemical composition is positioned on the exterior surface that reduces corrosion of the exterior surface.
- In one embodiment, the metal is aluminum, aluminum alloy, copper, a copper alloy, titanium, a titanium alloy, nickel or a nickel alloy.

- In another embodiment, the metal is steel. In a preferred embodiment, the steel is mild steel-1010.

Anti-Corrosion Protective Coatings

Some coating types that are particularly useful on steel are inorganic zinc and epoxy Inorganic zinc coatings are extremely good for preventing rust on steel. They are also excellent for providing protection from environmental factors like saltwater and harsh weather conditions. As a result, chemical plants and refineries often use such coatings to shield their equipment from deterioration. Additionally, zinc-rich primers can be coupled with super-durable polyester coatings in a vast array of colours—resulting in a finish that is both highly corrosion resistant and aesthetically.

Anodizing

Anodizing is achieved by submerging aluminium in an acid bath and delivering an electric current throughout the environment. A cathode is incorporated inside the anodizing tank and the aluminium in this setting serves as the anode. In this process, the oxygen ions are freed by the electrolyte to join the atoms of aluminium at the point that is anodizing. Therefore, anodizing is the process of extremely controlled oxidation or the enhancement of a natural or existing phenomenon.

Galvanic Corrosion

Galvanic corrosion (also called ' dissimilar metal corrosion' or wrongly 'electrolysis') refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. It occurs when two (or more) dissimilar metals are brought into electrical contact under water. When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone. Either (or both) metal in the couple may or may not corrode by itself (themselves). When contact with a dissimilar metal is made, however, the self-corrosion rates will change:

- Corrosion of the anode will accelerate Corrosion of the cathode will decelerate or even stop
- Galvanic coupling is the foundation of many corrosion monitoring techniques

Use of Inhibitors

Inhibitors are chemical substances used to reduce or eliminate corrosion. Inhibitors are used widely in the oil industry to prevent corrosion of steel by crude oils. Inhibitors based on chromates, phosphates, silicates, etc. are used to decrease corrosion of steel in aqueous media. Inhibitors must be replenished at regular intervals in stagnate environments and added continuously to solutions that are in motion, such as a pipeline. Adding inhibitors to a solution does not normally prevent corrosion by its vapours.

Use of Cathodic Protection

As mentioned earlier cathodic protection is used to reduce or eliminate corrosion by electrically connecting a more active metal to the metal that must be protected. For example, zinc and magnesium anodes are used to protect steel in marine environments. Cathodic protection is also achieved with the utilization of an impressed current (dc) and using a relatively inert anode. An electrolyte is, of course, needed for proper electron flow.

Use of Protective Coatings

Inhibitive Coatings

- Inhibitive coating systems are based on a prime coat containing a pigment known to chemically react at the surface of the metal.
- Red lead primers are probably the oldest, followed by the chromates, molybdates, lead suboxide and barium metaborate.
- Many of these are losing their position in corrosion control due to the personal and environmental concerns being raised over the last decade.
- Inhibitive pigments release soluble ions into the water that penetrate the coating film.
- These ionic species are carried to the metal surface and increase the polarization of the anode or the cathode.
- This process encourages the development of microscopic protective surface layers

Sacrificial Coatings

- Sacrificial coatings, usually limited to zinc rich coatings, rely on the incorporation of metallic zinc that will preferentially corrode or sacrifice itself to protect the steel substrate.
- These coatings take advantage of galvanic (dissimilar metal) corrosion as previously discussed.
- When in contact with the steel substrate, the zinc film serves as the anode of a large corrosion cell, minimizing any small electrical differences on the steel surface.
- The steel thus becomes totally cathodic to the zinc and is protected.

Barrier Coatings

- The barrier concept of corrosion protection is not based on the action of a particular pigment in the prime coat engaging in a reaction with the metal substrate.
- Barrier coatings function as primers, intermediates, topcoats or in thick-film formulations, as single coat "systems".
- Barrier coatings produce a tighter, more cohesive film, with lower permeability to water, oxygen and ions than inhibitive or sacrificial films.
- This properly ensures corrosion control even under the most demanding conditions including immersion in both fresh and salt water, burial in soils and highly corrosive chemical environments.
- Examples are coal tars, epoxies, multi-coat vinyls and aliphatic urethanes.

Protective Barrier Coatings

- Protective barrier coatings vary considerably in composition, performance and cost.
- The corrosion engineer has a wide choice of materials for most all applications and his selection will depend on the important requirements of the job.
- Many leading companies emphasize the importance of obtaining protection based on the lowest cost per square foot per year of service.
- In some cases, where short-term protection is needed, a barrier that would provide good performance for only that period may be quite adequate.