is sometimes used as a preliminary step in other cleaning methods.

2. *Alkali cleaning* is generally preferred over solvent cleaning. The solution can be applied by spray or soaking, depending on the size of the article. Alkaline cleaners are water soluble and are generally used at high temperature, although cold types are available.

3. *Emulsifiable solvent cleaning* is used to remove oils and greases. Emulsifiable solvents offer the advantage of flushing the soil away during the rinsing operation, leaving only a very thin film of solvent on the surface, which can later be removed if necessary. The emulsifiable solvents are either used in dip tanks or are sprayed or brushed on the surface and allowed to stand for a few minutes. The loosened and dissolved matter is then rinsed with water.

4. *Steam cleaning* involves abrading surfaces with high velocity impact of steam. This type of cleaning is very effective, but must often be augmented by wire brushing or sandblasting.

5. *Acid cleaning* generally consists of treating the metal with an acid containing oil solvents such as alcohols, ethers, ketones, etc., to aid in removing oil and oil-type products. Detergents and wetting agents are incorporated to assist in wetting the surface and removing soils. Acid cleaners of this type effectively remove grease, oil, and other surface contaminants, but acids alone are not effective on greases. This method differs from alkali or emulsion cleaning in that it removes light rust and minutely etches the surface of the metal, thus improving the adhesion properties of the coatings by providing a good mechanical base. The use of a phosphoric acid cleaner has the added advantage of reacting with the steel to produce a thin film of insoluble iron phosphate, which enhances paint adhesion.

If mill scale is too heavy, phosphoric acid solutions may require too much time, in which case, sulfuric acid pickling, may be employed where practical.

Shop Applied Coatings. Shop applied coatings offer the best overall opportunity for the best results. This is true because better conditions usually exist in the shop.

The use of a piece of equipment will largely determine the type of surface preparation and coating to be used. If the equipment will be used under very severe conditions, either by nature of the surrounding environment or the environment of its own manufacture, shop coating is recommended if at all possible.

It is at this stage that heavy members will probably be sandblasted and lighter members chemically treated. There are of course, many types of coatings available. In a broad sense, however, there are three basic types of environment, and three generic types of coating can be considered.

Normal mild atmospheric corrosion can be effectively prevented by alkyd resin systems. These systems can undergo less than perfect cleaning and still give reasonably good service. A vinyl resin system along with the best surface preparation is recommended when exposure to acid conditions is anticipated. If the equipment is to be used under severe alkali conditions, the best type coating will be a catalyzed epoxy.

Some of the advantages and disadvantages for each of the broad classifications are given in Table 3. A guide for coatings based on Federal Specification materials by end use is given in Table 4.

Field Applied Coatings. Field applied coatings can, in general, be of the same types as shop applied coatings. The limiting factor will be accessibility. Once equipment is in place, it becomes very difficult to use the type of surface preparation that will do the best job due to obstructions and accessibility.

Maintenance of Protective Coatings. Defects in a coating are virtually inescapable. These defects can be caused either by coating flaws in the film during application, or by mechanical damage after coating. In either event, the damage must be repaired in order to eliminate premature failure at these points.

Depending upon the severity of the service, an inspection should be scheduled after installation to detect mechanical damage. Damaged areas should be noted and repaired.

Table 3 . . . . Typical Paint Systems

Systems	*Advantages*	*Disadvantages*
Alkyd	1. Good adhesion to most substrates. 2. Skill required for application is minimal. 3. Reasonably high solids allow for maximum mil thickness in a minimum number of coats. High solids facilitate covering the anchor pattern so that proper protection is achieved. In general, alkyd formulations will take continuous operating temperatures of around 200 F.	1. The principal disadvantage is that they have only minimum resistance to acid or alkali contamination.
Vinyls	1. Excellent gloss and color retention. 2. The best known air-dry, thin film, acid resistant coating. 3. Excellent moisture resistance, both immersion and splash.	1. Relatively low operating temperature limit in ranges of 130–140 F. 2. In relation to other coatings, relatively low solids with the high in the range of 30 percent by volume. 3. Need for better surface preparation than other types of coatings because of poor ability to wet.
Converted or Catalyzed Epoxy	1. Excellent alkali resistance 2. High film build with minimum number of coats. 3. Chemical conversion assuring a better cure. 4. Excellent abrasion resistance.	1. Chalks readily, although not a degrading type of chalk, as would be experienced in oil films. 2. Always a two component system, necessitating a relatively short pot life.

Cathodic Protection

The cathodic protection principle is widely used to control corrosion in hot and cold water storage tanks, heat exchange water boxes, water and chemical processing equipment such as filters, reactors, and clarifiers, and the external surfaces of submerged and underground tanks, piping, and piling. Cathodic protection may be used with iron, aluminum, lead, stainless steels, etc. On new steel structures, optimum corrosion control design is often achieved by applying cathodic protection in combination with coatings, environment conditioning, or both.

The cathodic protection principle is unique in that protective effects can be directed from distantly positioned anode current sources onto existing submerged or buried structures. Corrosion control can generally be accomplished by cathodic protection without taking the facilities out of service, exposing the surfaces for coating, or specially treating the surrounding environment.

Cathodic protection, by definition, is the reduction or prevention of corrosion by making the metal the cathode in a conducting medium by means of direct electric current which is *either impressed or galvanic.*

Since this process superimposes the effect of an applied current onto an existing electrochemical corrosion system, its design must be adapted to meet the varying needs of the specific corrosion problem.[12] The electrochemical corrosion mechanisms to which cathodic protection can be applied fall into two broad classifications:

1. Corrosion of a metal surface by *stray* direct currents which flow in circuits grounded at more than one point or which flow in subsurface structures purposely made part of a direct current circuit.

2. Corrosion of a metal surface in an electrolyte by *galvanic* currents originating between discrete areas of oxidation and reduction reactions. Galvanic currents are the effect rather than the cause of corrosion.

While dissimilar metal couples, such as copper-iron, result in the corrosion of the more anodic metal, the corrosion cells formed by nonuniformities on a single metal surface or in the adjoining environment also conform to the requirements of the galvanic corrosion system.

Complete corrosion control by cathodic protection is approached when the net current flow at any point on the metal surface either measures zero or is flowing from the corroding media into the metal. It is not generally feasible to measure current flow directly at all points on a metal surface. A requirement for full cathodic protection is to polarize the cathode areas to the open circuit potential of the anodes.[13] The criterion for cathodic protection of iron is met when all points on the metal surface are polarized to a potential of −0.85 volts or more negative, measured against a copper sulfate reference electrode positioned at the metal surface.

The protective current requirements generally vary with factors influencing corrosion rates. Increasing oxygen concentration, temperature, and velocity increases protective current requirements. Resistive coatings, precipitated calcareous salts, adherent zinc or aluminum flocs, silt, and electrophoretically deposited particles all tend to reduce the protective current requirements.

Adequate protective current flow onto a surface from sacrificial or impressed current sources is equally effective in corrosion control.

Sacrificial Anodes. Coupling a more active metal to a structure will result in galvanic current flow through the corroding electrolyte, thereby providing a protection effect on the cathode surface. In providing the galvanic protective current flow, the more active metal is electrochemically consumed (sacrificed) and must be replaced. No outside power is required for protection.

Table 4 . . . . Guide for Coatings Based on Federal Specification Materials by End Use

Exposure	*Primers*	*Intermediate and Finish*
Dry Interior use	TT-P-636-B Synthetic Alkyd Primer	TT-E-489-B Gloss Synthetic Enamel *or* TT-E-508 Semi Gloss Synthetic Enamel *or* TT-P-51D Flat Alkyd Enamel
Exterior Exposure (normal weather conditions)	TT-P-615-B Basic Lead Silico Chromate Alkyd Primer *or* TT-P-636-B Synthetic Alkyd Primer	TT-E-489-B Gloss Synthetic Enamel
Interior-Exterior Heavy Moisture or Acid Conditions	*M. C. Primer* MIL-P-15328-A Vinyl Wash Primer *Primer* MIL-P-15929-A Vinyl Red Lead	*Intermediate* MIL-P-15929-A Vinyl Red Lead
Interior-Exterior Alkali Conditions	MIL-P-23377 Primer Epoxy Polyamide	*Intermediate* MIL-C-22750-A Coating Epoxy Polyamide *Finish* MIL-C-2275-A Coating Epoxy Polyamide

The properties of the more commonly used sacrificial galvanic anode materials are tabulated below.

Material	Theo. lb/(amp) (yr)	Actual lb/(amp) (yr)	Potential ($Cu-CuSO_4$)	Cost/lb (Approx)
Magnesium (AZ-63A)	8.5	17	−1.55 v	$0.35
Zinc (MIL-A-18001)	23	25	−1.10 v*	$0.20
Aluminum (B-605)	6.5	12	−1.05 v*	$0.30
Aluminum (ERP-HP7)	6.5	8	−1.20 v*	$0.50

* Sea water.

The sacrificial anode consumption is greater than the theoretical electrochemical equivalent of its protective current output. This is attributable to the self-corrosion current flow superimposed upon the protective current output.

The design of a sacrificial anode system is limited by the available driving voltage between the sacrificial anode and the structure to be protected. The resistance of the circuit between the anodes and the structure mainly determines the protective current flow. A high resistivity electrolyte requires a larger number of anodes than a more conductive electrolyte to obtain the same amount of protective current flow.

Sacrificial anodes are cast in various forms and weights in order to obtain optimum design and service life. Special backfills around the anodes are used in soils to maintain moisture at the anode surface and increase efficiency.

The zinc on galvanized iron provides a cathodic protection effect on the underlying metal until it is consumed in the protective process.

Zinc and aluminum anodes can usually be used in combination with well coated surfaces without accelerating coating damage.

Impressed Current. An external voltage source can be used to impress protective current flow from anodes through the conducting medium onto the corroding surface. Alternating current power, converted to direct current by an adjustable output selenium or silicon type rectifier, is most commonly used.

Sacrificial type anodes, such as scrap iron or aluminum, are sometimes used with impressed current. Nonsacrificial anodes (those not consumed by the electrochemical process), such as graphite, high silicon cast iron alloy, platinum or platinum plated or clad on titanium or tantalum, and silver-