Corrosion and Protection of Facilities and Infrastructures in Telecommunications Industry - A Review

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Abstract. A review of corrosion and protection of telecommunications facilities and infrastructures is reported here. The article gives a brief insight into the broad aspects of basic corrosion and telecommunications engineering and technology. These areas of discussion include all telecommunications metallic materials and equipment, buildings, and masts/towers. The review also discussed various corrosion protection methods such as organic/inorganic coatings, hot dip galvanizing, electroplating and electroless plating, cathodic protection, materials selection and systems design. The protection level for different components of the tower to which cathodic protection is used includes tower base, foundation of telecommunication shelters, buried portion of waveguide bridges, anchor shafts, and grounding system which were briefly discussed.

Keywords: corrosion; cathodic protection; telecommunication facilities; infrastructures; coatings.

1. Introduction
Corrosion is a major phenomenon responsible for degradation in many structural metals. It is defined briefly as destruction by electrochemical or chemical activities. It is broadly, the deterioration, degradation or destruction of a material or its properties due to interaction with a corrosive environment. This definition of corrosion includes both metallic and non-metallic materials; however, it is usually restricted to metals since metals have and will undoubtedly continue to be the engineering materials of major concern. Corrosion is, in general, a slow process but persistent in character. There are no metals that can withstand corrosive attack in all environments. It is now known that any metal can corrode under certain conditions of use and will ultimately be destroyed or rendered useless. Corrosion reduces the mechanical strength of metal/materials; and with the occurrence of extensive corrosion, failure ultimately results. This discipline is a major research area for scientists and engineers [1-14]. In aqueous industrial operating conditions and atmospheric environment corrosion is an interfacial reaction process. Corrosion reactions do cause damages and problems such as corrosion of concrete steel reinforcement leading to building and/or bridge collapse; occurrence of ugly sights and damages in ships and automobiles; cracks in aircrafts and structures etc. High temperature oxidation, another corrosion type, is the non-electrochemical corrosion process. It is also damaging to metals and alloys/components; and usually occurs in an environment (particularly air/oxygen) with elevated temperature. In this process, a much thicker layer of corrosion products is formed. Indeed, the cost of corrosion and protection world-wide is significant. The recent NACE studies of global corrosion cost are found to be US$2.5 trillion by estimation [15]. The studies described this cost finding to be equal to 3.4% of the total GDP worldwide in 2013. This cost is high, but it must be acknowledged that corrosion occurs, with differing extent of damage when metallic alloys employed in service interact with its environment. Corrosion, therefore, if not prevented, controlled and structures protected on time, has many unpleasant consequences to individuals and our society. The economic effect as mentioned above is of great concern to all national economies. Corrosion of structures is an even more significant problem. Complex metal structures and devices such as bridges, aircraft, automobiles, gas pipelines, storage plants, vessels, marine oil platforms, masts and buildings collapse could be detrimental. The economic impact of corrosion drives technological development at higher cost [16]. Materials are meant to be used in diversified environments in which many may be very unfriendly due to the emergent and occurrence of different forms of corrosion problems. These environments will include working at high pressures, elevated temperatures, seawater, alkaline and some other highly corrosive environments. It is required that
materials, particularly metallic materials must withstand such harsh and deleterious environments. In this circumstance, corrosion problems could negatively affect the creation and development of new technology. Corrosion problems like stress corrosion, fatigue failures, pitting and microbiological corrosions etc. depending on the environment will emanate. Corrosion of a metal generally occurs at two different of sites. This phenomenon can be explained by the diagram of Figure 1. There are the anodic sites and cathodic sites. The anodic sites are where the oxidation reactions occur and the metal goes into dissolution as ions and the reaction produces electrons in the metal. The cathodic sites are where the reduction reactions take place and where the electrons produced at the anodic sites are consumed. These “sites” together constitute a “corrosion cell”.

![Figure 1: Electrochemical cell showing anodic and cathodic sites on a corroding metal surface [16.]](image)

### 1.1 Corrosion reactions

Generally, the redox electrochemical reactions responsible for corrosion occurs at the same period of time at the metal/solution interface in any particular corrosive environment. In electrochemical corrosion, oxidation (anodic) reactions occur at the anode while reduction (cathodic) reactions occur at the cathode. A metallic corrosion such as the aqueous corrosion of iron at the anode can be represented as:

\[
(1) \quad \text{Fe} \rightarrow \text{Fe}^{2+} + 2e^{-}
\]

Cathodic reaction involves H2 evolution and O2 reduction show below:

\[
(2) \quad \text{O}_2 + 2\text{H}_2\text{O} + 2e^{-} \rightarrow 4\text{OH}^{-}
\]

\[
(3) \quad \text{O}_2 + 4\text{H}^{+} + 4e^{-} \rightarrow 2\text{H}_2\text{O}
\]

\[
(4) \quad 2\text{H}^{+} + 2e^{-} \rightarrow \text{H}_2
\]

The cathodic reaction represented by equation (2) shows example of corrosion in natural environments where corrosion occurs at nearly neutral pH values. Equations (3) and (4) represent corrosion processes. Where the pH can reach acidic values because of hydrolysis reactions a shown below:

\[
(5) \quad \text{Fe}^{2+} + 2\text{H}_2\text{O} \rightarrow \text{Fe} \,(\text{OH})_2 + 2\text{H}^{+}
\]

This reaction produces H+ ions, the concentration of which can under certain conditions become large if the H+ ions cannot readily move out from a confined volume. The very negative economic impact of corrosion on infrastructures due to its destruction of materials means that a good knowledge of the science of corrosion prevention and control is a necessity This is especially important in the highly capital intensive technological infrastructure like the telecommunications industry which is the focus of attention in this report.

### 1.2 Telecommunications technology and engineering

Telecommunications technology and engineering are among the most important of all modern technologies with their versatile and unparalleled diverse applications and contributions to the world civilization and economy. Telecommunications can be briefly described and/or explained to be the exchange or transmission of information by electronic and electrical means over a significant distance. In terms of changes in modern development, telecommunications can be regarded as the suite of technologies, devices, equipment, facilities, networks, and applications that support communication at a distance [17]. It is important to have a complete telecommunication arrangement which is made up of two or more stations equipped with transmitter and receiver devices. To achieve this, telecommunications devices/equipment among which are telephones, telegraph, radio, microwave communication arrangements, fiber optics, satellites, computers, and masts are used. In telecommunications, the United States Federal Standard 1037C has defined a facility as a fixed, mobile, or transportable structure that include (a) all installed electrical and electronic wiring, cabling,
and equipment and (b) all supporting structures, such as utility, ground network, and electrical supporting structures. These also include the real property which consists at least of buildings, structures, utility systems, pavements, and underlying land shown in Figure 2 [18].

![Figure 2: Telecommunications facilities and infrastructures [19 - 22]](image)

(a) The Tokyo Skytree mast [19]. b. Mast of an AM radio station in Mount Vernon, Washington, USA. [20]; c. Montage of the typical cellular Antenna at the top of the tower [21]; d. NITEL House, Lagos – the tallest building in Nigeria, is 160m tall with 32 floors. The communications spire hangs on top of the roof [22]; e. Antenna used for transmission of radio signals.

The importance of telecommunications in the society is well-known, accepted and very much understood. Some of the key areas of impact include that of providing sound foundation for communications; providing vital infrastructure for national security, and enabling participation and development. Telecommunications is of great importance within the national economy of a country [23]. The telecommunications-related industries are also a major employer, as there were communications services that employed 1 million U.S. workers in 2002, and thus representing 1.1 percent of the total private workforce. The communications equipment companies were said to have employed nearly 250,000 people [24]. However, it must be mentioned that the major telecommunications equipment and facilities/infrastructures are all made of materials and particularly metals. All these are subject to environmental deterioration, damage and degradation over a period of time due to corrosion reactions processes. It is therefore pertinent for all the telecommunications infrastructures to be protected to mitigate economic and technological disaster due to corrosion damage. Telecommunications facilities and structures due to their environmental locations as mentioned above do experience electrochemical corrosion phenomena. These include atmospheric corrosion; underground/soil corrosion; microbiological corrosion, concrete corrosion stress corrosion cracking and corrosion fatigue. The eventual consequence of these corrosion processes if facilities/infrastructures are not protected do result into serious damages with huge economic losses. With particular attention to telecommunications’ equipment, facilities and infrastructures, this paper reviews the various available methods by which this industry could be protected from the corrosive degradation phenomena and hence economic wastage. A report such as this could be of economic benefit especially to the relevant industry in the third world countries where insufficient attention is still being paid to infrastructural facilities’ corrosion protection.

2. Protective coatings of telecommunication facilities
Corrosion protection of different aspects of telecommunication facilities/infrastructure and equipment are necessary and this can be done by different means including the use of different coatings. Among the various coatings that can be used are:

(a) Hot dip galvanising
This is used to coat metals such as iron or steel by immersing them in a molten metal bath of low-melting-point metals like zinc, lead, tin and aluminium. Coated parts are usually thicker than in electroplating and can be heat-treated to form an alloy bond between the coating and the substrate. It is normally difficult to produce thin dip coatings; hence the coating is usually thicker than that of electroplating. Heat treatment of coated parts can be done to form an alloy bond between the coating and the substrate. The process of hot-dip galvanising has a number of advantages which include the ability to coat confined, internal surfaces, which would be inaccessible for coating by other methods. The hot-dip coating formation is by a metallurgical reaction between the molten zinc and the steel substrate. Subsequently, a series of hard, abrasion resistant iron-zinc alloys emerge that give a metallurgical bond between the steel and outer zinc layer. Depending on the product to be coated, there are various methods to perform hot-dip galvanising. Pre-treatment involves degreasing the steel to be coated, pickled in either sulphuric acid or hydrochloric acid, fluxed in a solution of zinc chloride and ammonium chloride and dipped in the molten zinc at a process temperature of between 440 and 465°C. The coating thickness of zinc is mostly affected by its molten temperature and the immersion time of the metal substrate. An example of hot dip galvanised products is shown in Figure 3.

![Figure 3: Galvanised tube products [25]](image)

(b) Electroplating
Electroplating is most commonly done to provision of protection from corrosion and for decorative purposes of a metal [26-28]. It involves coating of one metal over another by the use of electricity (hydrolysis); Electroplating on the surface of a metal is a versatile process which makes the chemical and physical properties of the surface to change. Electroplating can be used in a number of other ways that include changing the surface properties of an object for abrasion, wear and corrosion resistance and also for aesthetic qualities among others. Usually also called electrodeposition, electroplating may be referred to as a concentration cell acting in reverse. The electroplating process is conducted in the electroplating bath that consists of cathode and anode, immersed in an electrolytic solution. The anode is the metal that dissolves and is used for plating while the metallic object to be plated is the cathode. The passage of direct current causes the anode to undergo gradual dissolution. The resulting metal ions are reduced at the cathode where they are electrodeposited as coating on the metal. In general, the rate of anodic dissolution equals the rate at which the cathode is plated. The ions in the electrolyte bath are, therefore, subject to continuous replenishment by the anode [29]. Electroplating of zinc on steel is a typical example of a popular electroplating process which follows the principle described in the previous paragraph. Here, the anode is zinc and the cathode is the substrate metal where zinc is electrodeposited. Passage of current through the plating bath causes dissolved zinc ions to move through the bath electrolyte to deposit on the surface of substrate (cathode). The versatility and flexibility of zinc plating makes it possible for the plating to be done in different electrolytic plating baths that include chloride bath, alkaline cyanide and alkaline non-cyanide. Other specific types of electroplating such as copper plating, silver plating, nickel plating...
and chromium plating are used on iron or steel substrates. The process of electroplating or electrodeposition has been applied to telecommunications’ metallic materials components and facilities/infrastructures. The process also has wide applications in diverse industries such as in electronic equipment, airplanes, automobiles and many other aesthetic objects and ornaments. A schematic laboratory diagram of zinc chloride bath for zinc deposition on mild steel is presented in Figures 4 and 5. Similarly, Figures 5(i) and (ii) show the copper electroplating on a metal (Me) in a copper sulphate bath; and the zinc electroplating process respectively.  

![Figure 4: Schematic diagram of zinc electroplating in acid chloride bath](image)

![Figure 5: Electroplating process. (i) Copper electroplating on a metal (Me) in a copper sulphate bath, (ii) Zinc electroplating process [30](image)

(c) Electroless coating (plating)

This method had been variously used in many anti-corrosion systems and devices [31-33]. A review on the use and importance of this method was also recently reported [34]. Electroless nickel (EN) plating can be broadly described as a chemical reduction process in a bath without using electrical energy. The process is known to depend upon the catalytic reduction process of nickel ions in an electrolyte that contains a chemical reducing agent and the consequent deposition of nickel metal [35] This method is used to deposit a layer of nickel-phosphorus alloy on a metal. The alloys with different percentage of phosphorus, ranging from 2-5 (low phosphorus) to up to 11-14 (high phosphorus) have been reported to be possible in electroless coating [36]. The percentage of phosphorus involved determines the metallurgical properties of the alloys. In the EN plating process, a chemical reducing agent in solution has been explained to supply the driving force for the reduction of nickel metal ions and their subsequent deposition. This driving potential has been described to be essentially constant at all points of the surface of the component, but provided the agitation is sufficient to ensure a uniform concentration of metal ions and reducing agents [35]. Electroless deposits are therefore seen to be very uniform in thickness all over the part’s shape and size. A notable characteristic of this process is its ability to give uniform deposits in various metallic parts such as valves, deep recesses, bores, internal surfaces, blind holes and threaded parts [36]. There are other characteristics that are associated with electroless coating and these include excellent tribological, mechanical, and electrical properties and good corrosion resistance. [35-36] A typical EN plating process and accessories are presented in Figure 6.
Electroless plating process has wide application in industry on items which enable them to prolong the life of components exposed to severe conditions of service, particularly in the oil field, and marine sector. The other important uses include applications in aerospace hardware, automotive parts, and electronic components, telecommunication devices, and printed circuit boards. Electroless nickel is known [36] to withstand atmospheres salt water as could be seen with telecommunications towers/masts and others.

(d) Organic and inorganic paint coatings

Various paints and grades of paints are being used to paint the facilities against atmospheric, underground/soil and marine corrosion. Building and other construction works such as bridges facilities are included in the areas of application here. Paints of different colours can be used but conventionally, the red and white paints are more frequently used particularly for steel towers (masts) more for visibility purpose. It is important to mention that different specifications of coating thickness are used based on the areas of application for both the metallic and organic coatings. In a general environment, the standard film thickness of a coating has been described to be at least 125 μm and can be as summarized in Table 1 [38].

Table 1: Features and purpose of applied coating

| Layer            | Features          | Purpose/Function                                                                 |
|------------------|-------------------|---------------------------------------------------------------------------------|
| Maintenance of appearance | Maintain required appearance in terms of colouring, shine etc. |
| Upper coat       | Weather resistant | Control penetration of water/oxygen and resist ultraviolet rays, acid rain and acidity of volcanic gas (no anti-corrosion function) |
| Middle coat      | Concealment       | Conceal colour of lower coat and integrate lower and upper paint films          |
| Anti-corrosive action | Paint-film bonding | Prevent penetration of corrosive substances like water and salts; good at adhering to steel surfaces. |
| Lower coat       | Adhesion to steel surfaces |                                                                      |

(e) Cathodic Protection

Cathodic protection (CP) is a corrosion control method used to prevent corrosion of a metallic surface within a corrosive solution. The metal alloy requiring protection is termed the cathode within an electrochemical cell. CP is performed through the passage of electrical current into the structure from an external electrode which polarizes the candidate metal surface electronegatively. This phenomenon gives protection to the metal surface thus prolonging the lifespan of the alloy as shown in Figure 7. CP systems provide protection to large base of metallic structures.

Figure 7: (a) Cathodic protection of an underground tank and metal pipe using impressed currents (b) cathodic protection using sacrificial anodes [39, 40]
(f) Materials Selection

Materials selection is an important method used in the prevention and control of corrosion. Stainless steels have widespread applications in resisting corrosion; however, they do not resist all corrosives. It is important to know the “natural” metal-corrosive combinations in alloy selection. Some of these natural combinations which provide good corrosion resistance with less expenses include: tantalum – ultimate resistance; monel – hydrofluoric acid; titanium – hot strong oxidizing solution; stainless steels – nitric acid; steel – concentrated sulphuric acid; nickel and nickel alloys – nitric acid; lead – dilute sulphuric acid; hastelloys (chlorimets) – hot hydrochloric acid; tin – distilled water; and aluminium – non-staining atmospheric exposure [41]. Alloyed based metals such as nickel, copper, chromium and titanium are good for corrosion resistance in different corrosive environments.

(g) System Design

As important as the selection of materials, is the proper design of structure to mitigate or minimize corrosion. For effective corrosion control a good system design is necessary. To accomplish this, there are design rules to consider. It is appropriate to consider the type of material(s) to use, the operating, process, conditions, physical features and parameters and the environment where such will be used. Other design factors to consider are sealing or avoiding likely component corrosion susceptible areas and corrosion forms. Minimizing temperature gradients and stress gradients and maintaining separate environments are equally important [42].

3. Conclusion

This article presents a review and over-view of corrosion and effective corrosion protection methods that could be used to mitigate corrosion, preserve, and prolong the life of these capital intensive infrastructural facilities of the telecommunication industry. It describes specifically the use of coatings – organic and inorganic, galvanising, electroplating, electroless plating, cathodic protection, materials selection, and systems design to protect telecommunication facilities and infrastructures.

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