ASSET PRESERVATION – MOTHBALLING AND LAY-UP

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ABSTRACT

Infrastructure associated with power plant generation equipment is complex and expensive. Protecting this infrastructure from destructive corrosion during system lay-up and mothballing is a critical concern for future startup. Preserved infrastructure is also more valuable in the event of sale of the asset.

Of principal concern are mechanical, electrical, water handling systems and the combination of materials associated with these systems all of which require a concise approach to corrosion control. Corrosion of these components occurs for a number of reasons within an idle plant. In an idle condition, plants and associated equipment are subject to temperature fluctuations, water condensation and other conditions that cause corrosion to occur. Under certain combinations of conditions, corrosion can be very rapid. Without adequate control, corrosion can cause of number of problems. The bottom line is that the plant cannot be started up until these components are repaired or replaced.

Water that is left in cooling systems can cause corrosion from microbiological activity, oxygen availability corrosion related activity and galvanic corrosion from dissimilar materials. Water forms within electrical control panels and systems causing corrosion of the various metals utilized on computer boards and connections. Some of these conditions provide for more aggressive corrosion conditions than when the system is in full operation. There are concern for tanks, piping and electronic components comprising the fuel storage and delivery system. Corrosion of these components is unacceptable from both an operation and environmental standpoint.

This paper presents available technologies available for lay-up and mothballing in the power generation industry. Advantages and disadvantages would be presented and discussed.

I. INTRODUCTION

The direct cost of atmospheric corrosion in metals and alloys has been estimated to be at $5 billion annually (National Association Of Corrosion Engineers (NACE)). In the Utility segment of the US economy, the annual cost of corrosion has been estimated at $47.9 billion, with $6.9 billion in the electrical utility industry. Much of this corrosion affects active systems within the power plant and therefore becomes evident when corrosion related failures occur.

Power plant owners and operators may choose to mothball and/or lay-up operating systems and equipment for a variety of reasons. The equipment includes boilers, steam condensers, process heat exchangers, cooling towers, pipeline systems, tanks, fire water systems, electrical systems and heating and chiller systems. Theses systems and related equipment may be idle seasonally, during periods of over capacity, or for other reasons such as repair work on associated equipment.

Down time periods pose corrosion degradation related risks to the integrity of power plant systems that may be more severe than those in operation. Likewise, those periods when the equipment is being removed from, and returned to service, corrosion degradation is also possible presenting an increased risk. Conditions which support increased corrosion activity include absorption of atmospheric gases, accumulation of scale and corrosion products in stagnant areas, biological growth, and corrosion cells in stagnant areas and at water-air interfaces.

Corrosion remains active when systems within the power plant are shut down. Shut downs can be short term, measured in weeks, or long term, measured in years. The longer the shut down, more extensive corrosion damage should be expected. The longer term shutdowns or actual mothball and lay-up operations are put in effect when the generating asset is planned to be taken off line and the active systems turned off. Plants could be taken off line for a number of reasons and the time of inactivity may not be fully defined or understood.

In the cases where the power plant, or any of the off line systems will be utilized in the future as a results of demand changes, sale of the asset or other reasons, corrosion of these components needs to be considered. It is recognized that drained, de-energized, non-rotating and other idle equipment are susceptible to corrosion. A car that is simply parked in the backyard for a couple of years without any provisions for corrosion control and future operability, would not be expected to start up and run properly where desired. These types of problems are considerably magnified in a power plant.

The idle period should be determined in the early planning phase of the mothball or lay-up project. Both corrosion control processes and associated costs are influenced by the idle period duration as well as insurance company requirements. Of concern for the overall success of the program is the control of corrosion during the idle period that ultimately results. Should the idle period initially be determined to be 12-months, and then extended to 24-months, additional costs would be required for re-application of corrosion control technologies and equipment servicing that could increase the costs more than if the 24-month idle period was originally determined and planned for. More importantly, should the idle period get extended and corrosion degradation initiated leading to equipment failure, the program becomes a failure and the asset devalued.

In general, the following summarizes idle periods and relative costs:

Idle period duration	Relative cost
Up to 18-months	1.0
19 up to 5-years	2.5
Greater than 5-years	4.0

Table 1 – Idle periods[1]

There are several functional components that need to be considered in planning the mothball or lay-up program. Different corrosion control methods and procedures have varying requirements for power, heat and cooling, monitoring and other unique activities.

Operating personnel are initially required in the lay-up operation to perform equipment inspection equipment isolation, draining, lock-out tag-out, equipment cleaning and other functions. Personnel should be considered who have a vested interest in the success of the operation and preservation of the power plant asset.

Fire fighting equipment should remain in operating condition along with electricity and other support systems. Active systems would require monitoring and maintenance during the idle period.

II. FORMS OF CORROSION

There are many types of corrosion typically found in the power generation industry. Corrosion activity occurs as a natural reaction between a metallic structure and its environment. With available oxygen and water, or other chemical exposures, the material will under go a process called oxidation. When a metal experiences oxidation, the basic element of construction ie. iron, reacts with the hydroxide ion to form corrosion films. The most readily observed corrosion films are rust, iron oxide and copper patina. As the base material is consumed to form the corrosion films, the base material

experiences corrosion degradation, leading to loss of material.

Corrosion is established as direct current, DC, circuits. DC circuits are defined by the relationship called Ohms Law, E=IR, where E is the driving voltage of the circuit, I is the current magnitude and R is the resistance of the circuit. The greater the current flow in the corrosion circuit, the greater the metal loss. Ferrous materials (iron, steel, etc.) corrode at the rate of 20 pounds per ampere-year, other materials corrode at different rates.

II. – 1 General Corrosion

General corrosion will occur on structures exposed to several environments or electrolytes encountered in the power generation industry. Electrolytes include chemical, coal storage runoff, salt water and fresh water, soil of many varieties, atmospheric rain and air borne contaminants. Corrosion aggressiveness of these electrolytes is influenced by many contaminants contained in the electrolyte and concentrations of these contaminants[2].

The primary effect that contaminants have on environment corrosivity is a reduction in the environment resistivity. Lower resistivity, or circuit resistance, would produce larger corrosion currents for a given circuit. This can be seen in a modified Ohms Law where I=E/R. As the resistance decreases for a given voltage, the value of current increases. Field experience would support this relationship, for example, salt water environments are very corrosive as the resistivity is very low, conversely little corrosion would be found in uncontaminated dry sand.

II. – 2 Pitting Corrosion

Steel, or iron pipe including cast iron, stainless steel, copper and alloys of copper and other metallic materials corrode when exposed to electrolytes; water, soil and chemicals. The primary factor for these conduits is corrosion due to moisture and stagnating conditions. This type of corrosion typically results in pitting of the metallic surface and is particularly vicious when initiated in areas of coating faults. Of concern would be pitting activity that would lead to through-wall penetrations, resulting in loss of structural integrity, function and product[3].

Pitting corrosion loss of metal is far from uniform. Generally, there tends to be small areas of metal loss (pits) in larger areas of uncorroded or lightly corroded metal surface. The depth of pits will vary greatly. Usually there will be far greater numbers of shallow pits than deep pits. As pit depth decreases, the number of pits increase. As pit depth approaches zero, the number of pits approaches infinity. This is in agreement with the theory of extreme value probability.

Pitting corrosion initiates on the metal surface at points where coating holidays exist in the coating system or at anomalies on the metal surface where water/moisture conditions provide electrochemical conditions to support corrosion. Once initiated, the corrosion rate of a corrosion pit is aggressive due to the auto-catalytic nature of the chemistry within the pit. That is, the corrosion processes within an active pit produce conditions which are stimulating and contribute to continual corrosion activity within the pit. In stagnated moisture conditions, corrosion failures in several months have been documented.

In the industry literature, pitting rates are reported to vary for different materials and environments. Under some conditions, pit rates increase over time and in others, pit rate decrease with time. In soil, the pit growth rate tends to decrease with time and generally follows a power equation $P = kt^n$, where P is the depth of the deepest pit in time t, and k and n are constants[4]. Where soils are well aerated, n is low in the range of 0.1, and where soil are not well aerated, n is higher in the range of 0.9. Therefore in clay and fine grained soils, n is higher and the pit rate is greater that for sandy and large grain size soils. Where soils are not well aerated, and n approaches 1, the penetration rate is proportional to time.

II. – 3 Galvanic Corrosion

Galvanic corrosion results when two different metals are electrically or mechanically connected and surrounded by the same electrolyte. This is the electrochemical basis for the lead acid battery. The

material with the highest electrochemical energy level would experience corrosion, called the anode, and the other material, called the cathode, would not experience corrosion.

In the power generation industry, galvanic corrosion could be expected from connections between ferrous materials such as, steel and ductile iron, and copper, stainless steel and brass. In this corrosion cell the ferrous materials would corrode relative to the other materials. This relationship is normally depicted in a table referred to as the galvanic series.

The following table lists the common piping and construction materials in order of galvanic activity in a moisture bearing environment:

Material	**Potential***	**Activity**
Magnesium	1.70	Most active, Anodic
Steel	0.50 – 0.60	
Ductile iron	0.30 – 0.40	
Corroded steel	0.30 – 0.40	
Cast iron	0.10 – 0.20	
Copper	0.15 – 0.20	
Brass	0.15 – 0.20	
Stainless steel	0.10 – 0.20	Least active, Cathodic

* Potentials are electrochemically negative with respect to saturated copper-copper sulfate reference for water submerged and buried materials

Table 2 – Galvanic relationship water[5]

The following table lists the power plant structure materials in order of galvanic activity in a salt-water submerged environment:

Material	**Potential***	**Activity**
Magnesium	1.70	Most active, Anodic
Zinc	1.00	
Steel	0.60 – 0.65	
Nickel Cast iron	0.45 – 0.55	
Silicon Bronze	0.25 – 0.30	
Copper Nickel	0.20 – 0.30	
Monel	0.10 – 0.15	
Stainless Steel	0.0 – 0.10	
AL-6X	-0.05 – 0.05	
Titanium	-0.10 - -0.05	Least active, Cathodic

* Potentials are electrochemically negative with respect to a saturated silver-silver chloride reference for salt water submerged materials

Table 3 – Galvanic relationship salt water[5]

This chart indicates that for two dissimilar metals being electrically connected through mechanical connections and/or electrical connections, the one towards the most active end would be anodic and experience corrosion, and the one towards the least active end would be cathodic and not experience corrosion. For the corrosion cell to establish, both materials need to be in a common electrolyte and electrically connected through mechanical or electrical means. In the power plant environment, electrical continuity is common as a result of safety bonding and grounding of equipment.

II. – 4 Microbiological Corrosion

Microbiological corrosion manifests in aqueous environments from hydrotesting of pressure systems, wet lay-up during off-line periods and moist soil environments[6]. The microorganisms associated with microbiologically influenced corrosion, MIC, can begin to form within the first 2 to 4 hours of immersion in fresh or saltwater, continuing to mature and colonize throughout the system. Under these conditions, corrosion can occur due to the presence of bacteria. Microorganisms associated with corrosion require water for survival and energy from organic or inorganic materials for growth. They are very hardy, able to withstand a pH range of –1 to 10 and a temperature range of –4 to 210°F (-20 to 99°C).

MIC affects carbon steel, stainless steels, nickel based and copper alloy materials. Although there are many forms of bacteria that can influence MIC, the primary form is sulfate-reducing bacteria and iron-oxidizing bacteria. As they colonize on the surface of material, they alter the environment beneath the colony to one that is aggressive. Pitting corrosion is then the form of corrosion that is typically initiated under the colony.

III. CORROSION CONTROL – MOTHBALL AND LAY-UP

There are a number of control methods that can be employed to mitigate these corrosion problems. In general, available methods for corrosion control during mothball and lay-up periods can be classified in as (1) blanketing with an inert gas, (2) atmospheric alteration, (3) providing corrosion inhibitors to wet or dry systems, (4) films and greases[1]. These different system can be combined as required. There are advantages and disadvantages to each of these methods depending on several factors.

These can also be generally classified as active control and passive control. Active control includes blanketing with inert gas, keeping surfaces dry with desiccants or dehumidification system, and running the systems at a reduced rate. Each of these require power to (1) run the systems, (2) monitor sealed systems and pressures, (3) replace desiccants as they become saturated, or (4) maintain systems being operated at reduced levels. Passive control includes providing corrosion inhibitors to wet or dry systems. Inhibitors are introduced into the system components where they control corrosion through electrochemical reaction and barrier film protection.

III. – 1 Blanketing with Inert Gas

The use of inert gas to control corrosion of the internal surface of plant equipment can be an effective method. Inert gases can only be utilized in systems that can be sealed pressurized conditions maintained for the duration of the idle period. The most common gas used is nitrogen gas with very little oxygen and free of moisture. For complete corrosion control, oxygen content must be less than 1%.

Prior to the introduction of nitrogen, all components and interior spaces of the system must be dry and free of sediments, deposits and accumulations that could hold moisture. Once the system is dried and cleaned, the system must be restored to tight conditions. Inert gas requires that the system being treated is tight and capable of maintaining the positive pressure of the gas. The presence of the gas should be monitored through pressure instrumentation and is therefore considered an active method. All entry points must be labeled cautioning against personnel entry for protection against asphyxiation in low oxygen concentration spaces.

The corrosion control mechanism provided by the nitrogen is not a conversion of the existing atmosphere but rather maintenance of the cleaned atmosphere condition. This is achieved by the elimination of oxygen, a key component to most corrosion cells. Several strains of microbiological organisms do not need oxygen to survive and could therefore flourish. Where conditions not have been prepared properly at the onset of the lay-up or change over time, corrosion could initiate and remain active.

Effective oxygen exclusion requires purging of the original atmosphere by repeated pressurization with nitrogen followed by venting until the oxygen concentration is less than 1%.

III. – 2 Atmospheric Alteration

This approach to mothball and lay-up provides means to alter the environment to prevent excessive moisture accumulation. Moisture accumulation in the interior spaces of idle equipment results from condensation, ingress from rain/snow and incomplete system draining. In large piping networks and plant systems these conditions are likely to occur without knowledge.

Active means of moisture control include dehumidification, air conditioning and heat and the use of desiccants. Where the dew point can be maintained below all anticipated ambient temperatures, moisture would not occur from condensation. As these corrosion control systems require operating energy costs and active monitoring in the form of control systems, these are active methods.

These methods are generally more suited for electrical rooms, store rooms and other enclosed spaces. Each of these would offer advantages/disadvantages in different climate conditions. For example, elevated heat, typically 10°F, would not be utilized in a warm damp climate as the extra heat creates intolerable workable

temperatures, and corrosion would be more active at the elevated temperature.

To be effective, fans and other air movement methods must be put in place to ensure that all areas are effectively controlled. Any moisture that remains within the area being treated can cause corrosion due to the conditions discussed.

Desiccants are also available as an atmospheric alteration method of corrosion control. They function by removing moisture from the air by absorption into the desiccant material. These require that the system require draining and drying prior to use. Replacement is required on a routine basis as they reach their absorption capacity. In some cases, corrosion has been rapid where spent moist material has been left in contact with the metallic structure.

III. – 3 Inhibitors

Volatile corrosion inhibitors (VCIs) as utilized for mothball and lay-up projects are very useful as they can provide a wide range of application for the majority of the plant equipment[7]. These are materials with sufficient volatility to allow the enclosed space to reach equilibrium in all phases. They form protective films at both the vapor-metal and water-metal interface. Those in commercial use are often proprietary mixtures, but a representative material would be an amine salt of an organic acid.

There is a important difference between volatizing inhibitors and contact inhibitors such as nitrate. Volatile inhibitors volatize at temperatures from –20°F and up whereas contact inhibitors require elevated temperatures over 100 to 140°F to volatize. Nitrate and sulfate based contact inhibitors pose health and safety concerns where volatile inhibitors are environmentally friendly.

The success of VCIs relies on containment of the volatizing molecules within the space being treated. If they are allowed to vent out through open hatches and other appurtenances, the molecules will not be able to saturate the intended space and provide corrosion inhibition. A distinct advantage of volatizing inhibitors is that these can treat both submerged and atmospheric exposures at the same time. The equipment does not require extensive cleaning or drying prior to treatment.

VCIs can be introduced into the equipment in a variety of ways. These include powders, liquids and emitters that fit into electrical cabinets or small components, water-soluble bags, fogging, and wet lay-up. Upon return to service, the adsorbed protective layer will volatilize reducing startup costs.

III. – 4 Films and Coatings

Films and coatings include a wide range of materials that are utilized to isolate the metallic surface from the corrosive atmosphere. These can take the form of fully prepared and spray applied coatings to plastic wraps. There is a extensive range of film and coating materials that include volatizing corrosion inhibiting technology into the system to provide both isolation from the environment along with corrosion inhibition.

Films are used to cover, or encapsulate pieces of equipment to provide shelter from the elements. These are available in many forms including heat shrink, stretchable and bag. When using this type of material is become critical that moisture and corrosives are not included within the envelop with the product as this will promote corrosion. The addition of volatile corrosion inhibitors into the envelop space and the use of corrosion inhibiting plastic wraps provide corrosion control should water be trapped in the space or migrate in over time.

Greases, oils and petrolatum based products can be utilized on select equipment in the mothball process. Greases and oils can provide both lubrication and corrosion control. These applications are typically short term in their service life requiring reapplication. VCIs can be added to greases and oils increasing corrosion control.

Coatings that are applied for short term protection need to be applied properly. The are many types of temporary coatings that are available for lay-up operations. Surface preparation requirements range from power washing and hand tool cleaning to white metal blasting with abrasive grit. Some systems require two layer applications, primer and topcoat. These system become more labor intensive and

should be considered carefully in the development of the lay-up program.

III. – 5 Other Considerations

These processes address the equipment and structures that are either visible or have interior spaces. Soils create corrosive environments for buried structures particularly piping systems and tanks, underground or above ground. In many plants cathodic protection has been applied to these systems because they are steel, contain hazardous materials and may in many cases be regulated by State regulations for compliance.

Required testing of cathodic protection systems should be part of the mothball and lay-up program. Typically these systems require annual testing and evaluation for both sacrificial anode and impressed current cathodic protection. For impressed systems the AC power supply must remain active. Where the cathodic protection system is de-energized for the lay-up, ie drained condenser water boxes and other heat exchangers, the power supply should be shut off and tagged out.

IV. SUMMARY AND CONCLUSIONS

Corrosion prevention of idle power plant generating equipment during lay-up and mothballing is essential to minimizing the damage that can result after shut-down. There are several types of corrosion that can be experienced in idle equipment including that caused by the interaction of contaminants and oxygen, galvanic corrosion, and microbiologically induced corrosion. These conditions can cause pitting that may be the most serious form of corrosion.

There are methods to minimize the destructive effects of corrosion during lay-up and mothballing including inertion with nitrogen, atmospheric alteration, the use of volatile and non-volatile inhibitors, and cathodic protection systems. These methods can in some cases be effectively utilized in combination.

Careful evaluation of specific requirements for each system is required for effective corrosion prevention

V. REFERENCES

1. R. J. Twigg, “Guidelines for the Mothballing of Process Plants”, Materials Technology Institute of the Chemical Process Industries, Inc., MTI Publication No 34, 3rd printing 2002.

2. W. J. Gonzalez, “Implementing the Proper Lay-Up Procedures for Industrial Boilers and Their Auxiliaries”, Watertech ’95, Houston, TX, November, 1994.

3. S. H. Paul, “Minimizing Infrastructure Deterioration”, Journal NEWWA, Holliston MA, June 2001

4. H. H. Ulig, R. Winston Revie, “Corrosion and Corrosion Control”, Wiley Interscience, Third Edition 1985, Chapter 9

5. “Corrosion Basics and Introduction”, NACE International, 1984

6. G. Kobrin, Editor, A. A. Stein, ”Microbiologically Influenced Corrosion”, NACE International, 1993, Chapter 3

7. B. A. Miksic, “Use of Vapor Phase Inhibitors for Corrosion Protection of Metal Products”, CORROSION/83 (Houston, TX: NACE International, 1983).