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Review Article

Corrosion and its Control in Agricultural Facilities and Equipment

.

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Abstract

Corrosion is ubiquitous and ravages all sectors of world economies of which agricultural industries are not immune. Techniques abound to stop corrosion theoretically and practically however, human errors and over enthusiastic application of available methods of protection have reduced their applications to practical reduction of corrosion rates of materials of construction. This review highlights chemicals and agricultural wastes which enhance corrosion rates of materials of construction and practical ways of reducing their effects.

Keywords: Corrosion inhibitors, fertilisers, aluminium, stainless steel, mild steel, pesticides, silage.

1. INTRODUCTION

One of the largest sectors of world economy is the agriculture and horticulture industry. They are quite capital intensive. Investments per acre are varied, depending on the type of activities involved. It is not easy to define exactly where corrosion can be most damaging in agriculture due to the diverse nature of structures, machinery and fittings employed for farming purposes. This is further compounded by environmental factors such as rural, urban and coastal indices. Also of concern are climatic, type of farming activities as well as the seasonal use of specific equipment and machinery and the various storage methods employed [1].

The degree of corrosion of a metal is largely dependent on the environment in which it is put to use. The atmospheric behaviour of metals in wet conditions and in soil differs, therefore protective treatments must be chosen in accordance with environments. While it is appropriate to use temporary protection such as grease impregnated with or without corrosion inhibitors, it is more important to select materials which can withstand the type(s) of corrosion envisaged in a particular environment. It will be inappropriate to use copper and its alloys in environments laden with ammonia or its derivatives so also stainless steel equipment in chloride environments. They will suffer from stress corrosion cracking (SCC) [2].

In designing buildings and structures, the corrosiveness of the atmosphere must be assessed. Expectedly, coastal areas are considered to have higher corrosion tendencies than those inland. This is also applicable to tall structures and those sites exposed on hillsides. Likewise it is believed that corrosion is more prevalent downwind of industrial areas which are always laden with nitrous and sulphur oxide gases which promote acid rains [3]. Studies [4] have shown that corrosion damage is not always uniform in nature and it is usually localised to small areas resulting in premature failure or damage. Such failures are usually associated with microbiologically influenced corrosion (MIC). Prevention could be

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achieved through good design and the adoption of best practice and good house keeping in equipment use.

2. CORROSION BY AGRICULTURAL CHEMICALS AND THEIR CONTROL

Fertilisers, grains and silage preservatives, pest chemicals, disease and weed control, and proprietary acid solutions for cleaning dairy equipment are common examples of chemicals largely used in farming.

Farm wastes and slurries are known to be considerably corrosive. Also, chemicals most significantly damaging to farming structures and machinery, are acid preservatives, additives, some fertilisers and manures/slurries. As regards acid cleaning chemicals, these can be used along with eco-friendly and bio-degradable corrosion inhibitors in order to reduce their damaging effects [5-10].

There are different types of fertilisers with varied levels of corrosiveness. The determinants of corrosiveness include the decomposition or reactions to produce aggressive substances such as ammonia or hydrogen sulphide; especially where chloride ions are present like potassium or ammonium chloride or where acidic conditions are prevalent. For instance, ammonium nitrates or di-hydrogen ammonium phosphate are known to engender material degradation through hydrolysis to acids resulting in a fall in pH. The ratio of essential plant nutrients could affect the degree of corrosiveness of compound liquid fertilisers. It is believed that the effect is most evident with fertiliser solutions containing about15% nitrogen; more so when half the free nitrogen is derived from urea and half from ammonium nitrate.

A study [11] shows that for fertilisers containing nitrogenous solution of ammonium nitrate and urea reacts only slowly with steels and the reaction becomes more rapid at welds and bolt holes. Welded steels suffer from depletion of alloying components at the heat affected zones (HAZ) and bolt holes constitute crevices where corrosion will be more intensified. In the same study, it was shown that phosphate solutions containing ammonium phosphate are less reactive towards steel, forming a phosphate passive layer which protects the underlying substrate.

When fertilisers are dry, there is zero or very minimal corrosion. However, because of their hygroscopic nature they can easily attract moisture thereby becoming corrosive. The point at which fertilisers become hygroscopic, the relative humidity (RH) at and above which moisture is absorbed changes depending on the compound. The lower the compound's RH value, the more corrosive the fertiliser is likely to be. Ammonium nitrate begins to absorb moisture at 60% RH, some other phosphates only absorb moisture when their RH values are above 90%. Initial contact with moisture causes fertilisers to cake causing a marked increase in its abrasive properties. To encourage increased resistance to corrosion it is advised that steel be galvanised. Evidence abounds in tests where it was shown that fertiliser chemicals are more aggressive towards mild steels than towards galvanised steels [12]. Corrosion rate values quoted for 63% saturated ammonium nitrate solution are about 250 mm for galvanised steel as against 1,250 mm for mild steel in the first year of exposure. Carbon steel provides a cheap option for the containment of fertilisers, as long as adequate surface cleaning, preparation and coating are done. Type 304 stainless steel was observed to be of most benefit for liquid fertiliser service from tests done over a three-year period. Penetration values quoted for tanks exposed for about 2.5 years to commercial liquid fertilisers are in the region of 0.253, 282 and 132 µm for Type 304 stainless steel, carbon steel and 5052 aluminium respectively.

A better control of the onset and progression of corrosion by fertiliser solutions can be achieved through better design of equipment and enhanced maintenance and cleaning. Also, the use of inhibitors with fertilisers during storage, transportation and application also help reduce corrosion. Sulphur compounds, like thiourea, ammonium thiocyanate and 2-mercapto benzothiazole, are known to be suitable inhibitors for mild steel exposed to a mixture of ammonium nitrate-ammonia-water system in the absence of urea. Relative

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successes have been reported with the use of polyphosphates such as sodium polyphosphate, dibasic ammonium phosphate, for aqueous ammonium nitrate/ammonia/urea. However, free ammonia can reduce inhibitive effects of orthophosphate by reacting with it to form a complex salt. [7]. In addition, there is a huge abundance of renewable inhibitors of plant origin which are readily available for use in agricultural settings.

Organic acids produced during the process of ensilage can cause corrosion damage in tower silos. The general assumption is that the most acidic and corrosive environment are observed within silos containing whole crop maize silage, due to speedy fermentation thereby producing acids with typical concentrations in solution of 2% lactic acid and 0.5% acetic acid and with pH as low as 3.6. Lactic acid is a stronger acid and where oxygen is present, secondary fermentation may occur, resulting in silage with predominantly butyric acid, which gives a relatively higher pH value. However, corrosion rates inside silos are usually higher than those on the external walls because temperatures inside silos are usually higher than those in the outside environment. This is understandable since every 10°C rise in temperature doubles the rates of reaction including corrosion reactions.

Formic acid has been used extensively over the years to prevent the growth of moulds and bacteria on stored grains. Other acids in the aliphatic carboxylic group, including propionic acid, have also been employed. Generally, the contact time for acids on machinery for example on augers and balers, is quite low, hence corrosion rates are usually very low on mild steel. Propionic acids are highly corrosive, however, damage could be minimised if the right precautions such as the complete removal of the acid-treated grain from the silo after use, washing with water, and avoidance of contact of treated grains with unprotected machinery.

During storage, acid-treated grains are less prone to cause corrosion, the major precaution needed being to minimise the risk of concentration in local areas such as crevices, or where stagnant pools of liquid can easily collect [13]. These are detrimental to metals as a result of differential aeration corrosion in such crevices.

The problem of paint-stripping properties associated with organic acid additives can be contained by the modification of their compositions. For instance, an addition of a cation to produce complex acid salts makes it considerably less corrosive and less liable to strip paint. It has been observed that aluminium provides as much as 10 years life service for silos. Another material with such viability is vitreous enamelled steel which is particularly easy to clean and maintain. Plastic coatings are prone to surface damage, and crevice corrosion could easily occur if adhesion is lost. It is probable that galvanised steel may deteriorate when in contact with silage juices and slurries, though resistant to silage vapours. Aluminium is the most preferred metal for the construction of storage vessels, followed by galvanised steel and then mild steel [14].

Usually silage from the bottom of the silo has a consistency akin to chipboard therefore equipments used for conveying and unloading silage can be subjected to corrosive wear. Abrasion and acid attack are also particularly destructive to concrete as acids are known to react with lime which causes the concrete to become friable. Thus, this encourages the concrete to crack and eventually spall further exposing the internal structure to inclement weather. Other ways of providing protection against corrosion is by covering floors with plastic sheeting, or with an acid-resistant coating such as chlorinated rubber or epoxy paint.

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2.1 Corrosion by slurries/manures and its control

The spiralling growth of animal husbandry comes with a simultaneous growth in the problems of handling manure. To this end large numbers of equipment have being developed using suitable materials to cope with the large quantities of animal waste

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involved. To combat excessive corrosion in crevices and awkward corners, round section tankers and other equipment should be encouraged from the design stage.

Slurry is a mixture of dung and urine while farmyard manure (FYM) is slurry composted with litter, which may be a mix of straw or wood shavings. On fermentation these release moisture, ammonia and carbon dioxide. Urea, uric acid, ammonia and ammonium salts, which are naturally excreted chlorides, are the major corrosive constituents in slurry and FYM. These mixtures are corrosive to steel structures and machinery that are not well protected and maintained. Results [12] have shown that galvanised steel is not significantly beneficial for some manure, especially those derived from poultry and cattle. However, manufacturers still favour the use of galvanised steel or concrete for livestock floors. In the case of piglets where copper compounds are incorporated in the feed, tests results show that galvanised metal thickness losses are close to 0.1 mm/year. This could be attributed to the effect of local deposit/galvanic corrosion. It has been observed that when there is a mixture of silage effluent and slurry a dangerous concentration of hydrogen sulphide gas can be formed which will encourage the formation of corrosive acids under deposits.

2.2 Corrosion by herbicides and pesticides and its control

The past decade has witnessed an enhanced growth in the development of chemicals for the use of crop protection. Simultaneously, there has been growth in corrosion by herbicides and pesticides. This is significantly noticeable under certain conditions, especially if harmful species concentrate in local areas. A common feature associated with incompatible metals is that copper-bearing fluids such as Bordeaux mixture an outcome of a mix of copper sulphate, water and lime is quite aggressive to aluminium or zinc as well as galvanised steel. This could be very harmful on new structures that have been freshly galvanised. Evidence from glasshouse structures shows that there is a significant increase in ‘zinc drip’ with the use of such copper-bearing fluids. It can be inferred that local deposits of copper will encourage the anodic dissolution of zinc in a suitable electrolyte hence the observed “zinc drip”.

Serious waterline attack may occur on steel drums containing aqueous TCA, sodium trichloroacetate-weed-killer within a nine month period and heavier attacks have been observed on aluminium, galvanised steel, various brasses and copper while tinned steel and molybdenum-containing stainless steel Type 316 were more resistant which essentially should be the preferred choice in the combat against corrosion. Common weed-killers like nitro-phenolic compounds, of general formula 2,4-dinitro, 6-alkyl phenol are known to have corroded steels and irons used in spraying equipment, both in aqueous or oleaginous dispersions. Covering surfaces with oil will provide better inhibition against waterline attacks. Again, inhibitors such as 0.7% sodium dichromate (for TCA) and 1.5% furfural (for 2,4-dinitro) have been found useful and currently, they have been implicated to be harmful to human and the environment at large.

Some insecticides like chlordane are found to be very corrosive with acidity, in the range of pH of about 2 as well as aqueous solutions of sodium arsenite and DDT in salt water. These are known to be aggressive to common metals like carbon steel, galvanised steel, copper and aluminium. Stainless steel is reported to be the most resistant for use with herbicides and pesticides while aluminium is found to be satisfactory in all with the exception of aqueous sodium arsenite. Insecticides dissolved in kerosene or fuel oil are found to be less aggressive as the solvents are of petroleum origin and could coat the surfaces of metals with a thin film in which case they perform the functions of inhibitors.

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2.3 Corrosion and its control in dairy farming

The use of stainless steels is wide spread in the dairy industry. Expectedly corrosion in this area is limited and relatively uncommon. However, specific problems may arise with cleaning and sterilisation of buildings and machinery, hence the need to protect steel structures from milk wastes. Lactic acid, for instance can easily corrode 1.25 mm of steel within a year. Agents containing chlorine, such as sodium hypochlorite disinfectant are potential corrosives to most metals associated with dairy industry equipment. Concerted efforts should therefore be taken to minimise the build-up of chloride ions that are destructive to metals and can easily weaken the natural protective films on the metal surface. Some stainless steels tend to crack through stress corrosion when in contact with chloride ions and/or caustic solutions under conditions of tensile stress and temperatures above about 70 ^{o}C [2, 15]. It is not advisable to use phosphoric acid in the removal of scale or milk stone in aluminium-based utensils and tinned surfaces should not be over-treated as this will cause tarnishing which may discolour the dairy products.

3. Corrosion and its control in high risk prone areas

In a recent survey of farmers and horticulturists it was found that corrosion damage to buildings and structures are comparable with damage to machinery and equipment. Evidence shows that metals like galvanised structures and sheeting, certain animal houses – notably piggeries – and units that handle fertilisers and slurries are high-risk areas where the influence of chemicals often in association with wear, can be significant.

3.1 Structures and buildings

Corrosion occurs in galvanised structures when the protective zinc coating has been removed by acids or salty environments or any strong alkali. This is true, as galvanised sheets in rural environments could last more than 30 years, while in comparison the life span in a severely polluted, industrial area may be only five to ten years where acid rains are implicated as the agents of corrosion [16]. On the other hand, aggressive soils like peats or marshes containing sulphate and chloride or acid conditions engender higher corrosion rates in galvanised steel than may occur at ground level in some buildings. Also galvanised steel can neither withstand the severe condensation that is very common in farm buildings. It is often recommended that buildings sited in marine or other highly corrosive atmospheres should be painted. Consistently, calcium orthoplumbate alkyd primers with a matching alkyd top-coat/ acrylic resin dispersions and paints based on combinations of Tung oil and alkyd phenolic resins have been observed to be easy to apply and performed creditably well on galvanised surfaces.

Corrosion in piggeries and poultry houses has been attributed to intense slurry action where the internal atmosphere contains ammonia in high concentration. The use of double layers of roof sheeting with an air-space in conjunction with improved ventilation using air-space and air inlets in walls and outlets in the roof, or the use of materials less prone to corrosion, with or without protective coatings is basic designs aimed at reducing condensation effects beneath roof surfaces. An adequately ventilated piggery will remove gases, dust and odour, while air temperature and relative humidity will be controlled. In addition, excess heat and moisture will be controlled which will ensure appropriate oxygen levels. Naturally ventilated sheds should be separated by a distance of five times their height to maximise ventilation [17]. It is advised that adequate caution be taken for fixings and fasteners for all structures, whether they are metallic or not.

Corrosion in crevices could be problematic, and corrosive reactions occur if aluminium or zinc (on galvanised steel) come into direct contact with timber, especially if treated with preservatives containing copper, mercury or fluorides in damp conditions. Copper and

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mercury are cathodic to most metal thus when these are short circuited, the anodic, more active metal, aluminium or steel will corrode preferentially as a result of galvanic corrosion.

Options for the control of damage to metals in contact with timber include the isolation of the area with a suitable tape or bituminous layer, by dipping the metal in lanolin or tallow prior to fitting. Some timbers are naturally durable and are viable for diverse situations, including contact with the ground or other damp material. *Jarrah* and teak could last for over 50 years whilst other timbers such as chestnut, pine or cedar can have a life span of up to 20 years. Most timbers used for glasshouses in Europe are red wood, which are well preserved with preservative to underscore the risk of decay [18]. It is recommended that in cases where timbers are not treated with preservative they should be painted however, neither creosote nor emulsion paint should be used because they are detrimental to growing crops. Emulsion paints contain a lot of poly vinyl acetate. Acid vapours emitted by timber as part of the natural seasoning process are known to corrode metals nearby while actually not in contact in environments that are not well ventilated. This is common with woods like oak and sweet chestnut and should be avoided in combination with metallic surfaces of structures.

Active chemicals from poultry and pig farming can undermine the life span of farm fencing which usually have an average span of up to 14 years. Generally, galvanised steel has a longer life span than wood and mild steel for fences and gates as reported by Loto and co-workers [12]. It is also known that zinc used in cereal farms where there is a high usage of lime and chemical sprays are prone to heavier attacks. This may be due to the fact that zinc is anodic to mild steel and the zinc particles will only protect mild steels in its immediate vicinity while other larger unprotected areas will be left to the ravages of corrosion giving an uneven corrosion patterns.

Premature failure could occur in gutters due to poor maintenance, or poor locations during erection. To forestall such premature failures, sloping guttering design is favoured in order to minimise the formation of silt deposits and also to avoid the accumulation of pools of stagnant liquid which are most likely to be acidic solution from cleaning procedures.

3.2 Equipment and machinery

Considerable care should be taken of machines that handle chemicals especially, artificial fertilisers and slurries as they are the most vulnerable to corrosion. To this end quality maintenance and care of machinery during and after use and particularly during out-of-season storage is encouraged. Corrosion could be responsible for a variety of defects, seizure of moving parts, distortion of metering equipment, blocked outlets which can seriously affect or cause the mal- function of machines; hence undermining the even distribution of fertilisers. Poorly drained areas tend to be more corrosive as they are likely to remain damp and dirty especially in overlapped joints, on spot-welds and in crevices. Such crevices when filled with or without contaminated electrolytes create differential aeration corrosion at which points corrosion rates are more severe. Hence better management of corrosion could be achieved with regular cleaning and good storage. Best results can be achieved from thorough hosing down with water after use and in particular from the removal of mud poultices. When the hosed environment is dry, oil or grease should be applied. A wide range of temporary protective options abound. These include short-term inhibited oils and greases to long-term hard film systems and supplementary sealants like those used on the undersides of vehicles.

The choice of materials for the manufacture of agricultural equipment is governed by many factors; designers consider the materials resistance to the weather and farm chemicals, its strength and ease of manufacture. Other considerations may include resistance to rough handling, cheapness and accessibility. Corrosion-resistant metals are not necessarily uneconomic, nor are plastics too weak; nylon, polypropylene and acrylonitrile butadiene styrene (ABS) are all suitable for many agricultural environments [19]. The importance of

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design detail cannot be overstressed, as examples, the sealing of overlapped joints with elastomeric sealant, and the provision of generous working clearances at hinges to allow easy greasing, could each contribute quite a lot to the life of a piece of equipment. From corrosion experiments, it has been observed that galvanised steels withstand the effects of agricultural wastes from livestock more than its mild steel counterpart [12, 20].

4. CONCLUSION

For machinery and equipment adequate cleaning and application of temporary corrosion protection with the use of inhibited oils and greases prior to storage in a well assessed facility is important to avoid damaging corrosion effects.

Location of agricultural sites should avoid heavily polluted industrial and salt laden coastal areas; different environments will induce different corrosion rates on materials of construction.

Both external and internal surfaces of buildings and structures should be well protected with paints and coatings suitable for the environment and stagnant conditions should be avoided. Also designs which encourage condensation must be avoided.

Agriculture or farming environment is hard on machinery and facilities thus their consistent protection is required from the daily exposure to water, fertilizers, cow manure and pesticides. Hence known and rigorously tested methods of corrosion prevention should be applied while in use and stored during seasons.

Good house keeping is of the essence in agricultural establishments for the reduction of damaging effects of corrosion.

COMPETING INTERESTS

"Authors have declared that no competing interests exist.".

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