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FUNDAMENTALS OF CORROSION CONTROL DESIGN

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FUNDAMENTALS OF CORROSION CONTROL DESIGN^(a)

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INTRODUCTION

Faulty design is often a major factor leading to corrosion and loss of utility. An understanding of the role that design plays in corrosion prevention will help ensure that the facilities, structures, and equipment designed will fulfill their intended purposes. The desired systems will last as long as necessary, have required reliability and also retain good appearance in those situations where esthetics are a major concern. As a general condition there is a close correlation between good corrosion design and cleanliness; those systems that incorporate these design principles are usually either cleaner or easier to clean than those that do not. The use of anti-corrosion design principles also provides balanced economics that will produce a minimum cost when capital and operating expenditures are both considered. Another significant consideration in the examination of system economics is the knowledge that appropriate remedial action during the design stage has a minimum overall expense whereas changes to the system or equipment at a later date can result in prohibitive costs.

The primary thrust by designers and architects in combating corrosion has been through the specification of resistant materials and providing a corrosion allowance by calling for added wall thickness. In their reliance upon specification and wall thickness, designers frequently have overlooked design techniques that avoid or control corrosion. Another factor contributing to the limited use of these techniques is what appears to be an occasional conflict between designer goals and those that are of greatest operator benefit.

The effects of design have been under study for many years. Some of the basic concepts were stated as early as 1947. A summary of their continuous development will be presented. Because these effects have been, in most cases long recognized, generalized principles will be presented that should provide a framework for the design of systems, structures and equipment. Subsequent discussions will be centered on examples of good and bad design practice, remedies for those unfortunate cases of bad design and different system needs.

(a) Some of the material in this paper was presented in a paper entitled, "Introduction to Corrosion Control Design," by Lyle D. Perrigo and was given before the Sixth Western States Corrosion Seminar, National Association of Corrosion Engineers, in Pomona, California, May 2-4, 1972. Subsequently it appeared as an article in the proceedings of that meeting published by the National Association of Corrosion Engineers, 2400 West Loop South, Houston, Texas.

No attempt will be made to enter into a discussion of corrosion mechanisms. The general nature of crevice corrosion, galvanic attack, general corrosion, effects of oxygen and other forms of corrosion which are important to this presentation on corrosion control design can be found in the literature.(1,2,3,4)

CORROSION CONTROL DESIGN DEVELOPMENT

In their pioneering article in 1947 Mears and Brown identified many of the elements of corrosion control design used today.⁽⁵⁾ The effects of air-liquid interfaces, contact between wet porous materials and metals, different joining techniques, deadlegs and crevices, various procedures for supporting tanks, holdup of fluids by structurals, and drainage and cleanliness were discussed in this early article. Reinhart added emphasis to this field of study with an article on corrosion design in 1950.⁽⁶⁾ The various effects of different climatic conditions were noted in the early 1950's.⁽⁷⁾ Emphasis by the U.S. Army on improving equipment reliability focused additional attention on corrosion control design.⁽⁸⁾

For several years occasionally articles appeared that expanded earlier coverage and promoted an increased understanding of the importance of design in controlling corrosion. The Australians, Hopkins, Anderson and Watson published material in 1965-1967 on the importance of design in avoiding corrosion problems on bridges, buildings and various facilities.⁽⁹⁻¹¹⁾ A number of Americans and others followed with publications in the later 1960's and early 1970's relating experience on a wide variety of systems or presenting concepts on how design could be used to control corrosion.^(4,12) This recent increase in publication has coincided with a greater recognition of the value of avoiding as many corrosion problems as possible at the design stage.

The food industry developed an early appreciation of the effects of design on system cleanliness. Because cleanliness was an important factor in public health and food quality, legislation was enacted that established standards of cleanliness. The beginning of sanitary science has been attributed to the passage of the Food, Drug and Cosmetic Act by Congress in 1938.⁽²¹⁾ The systematic examination of design effects and the emphasis placed on avoiding crevices and deadlegs, promoting self drainage, having vents and providing proper layouts to promote good housekeeping resulted. These developments preceded Mears and Brown, although paralleling their findings in many respects. The common elements of these two design philosophies and their effects on corrosion were first noted by Perrigo in 1972.⁽¹⁹⁾

CORROSION CONTROL DESIGN PRINCIPLES

Over the years, perceptive corrosion engineers and designers have developed principles that if applied during design, will reduce or avoid corrosion. These principles came from observation of equipment and system failures and experiments with different orientations, configurations, and procedures to avoid similar problems. Consequently these principles are based upon pragmatic considerations and should have a broad and general

utility. Table 1 lists these principles as noted or stressed by a number of authorities who have examined this subject. (3,4,5,9,13,22)

TABLE 1. Corrosion Control Design Principles

- When locating facilities, choose the least corrosive environment.
- Avoid crevices.
- Join by welding rather than riveting.
- Design for easy draining and cleaning.
- Design for easy component replacement when rapid failure in service is expected.
- Avoid excessive mechanical stresses and stress concentrations.
- Avoid contacts between dissimilar metals.
- Avoid sharp bends in piping systems.
- Avoid heat transfer hot spots.
- Exclude air from systems.
- Avoid contacting metal surfaces with absorptive materials.
- Avoid complex system configurations.
- Avoid sharp edges for systems that are to have protective coatings.
- Keep surface-to-volume ratios low.

There are exceptions to these principles; for example, titanium and stainless steels are more resistant to acids containing dissolved oxygen or other oxidizers. Such conflicts will be treated in greater detail in the section on different system needs.

LaRocca's list for sanitary design in the food industry is similar. (23) Construction in the product zone should have no recesses, dead ends or open seams, crevices or gaps, protruding ledges, shoulders to form pockets, dissimilar metals or exposed inside threads. He calls for continuous smooth welds and a self-drain pitch to pipes.

GOOD AND BAD PRACTICE

Examples of good and bad design practice are discussed in subdivisions following classical elements of design: site selection, location, layout, structurals, joining, vessels, piping, floors and process conditions. An arbitrary distinction has been made, however, between site selection and location that normally would not exist in any discussion of the elements of design. This has been done here to focus attention on the differences as well as the similarities involved in placing facilities within broad geographic regions and very small areas or perhaps even one specific piece of real estate.

A number of figures are used to show differences between good corrosion control design and those cases where such principles are not employed. The examples given in these figures have been developed from those situations most frequently encountered in industry or by the public and which are, therefore, of broadest general interest.

SITE SELECTION

The location of facilities and plants is an important consideration in corrosion prevention because of the variation in the corrosivity of various environments. For siting purposes these different environments may be considered as falling into three general classifications, industrial, rural, and marine. The effects in all are primarily governed by moisture levels and oxygen, but are accentuated by contaminants such as salt and air pollutants.

To realize the best economic balance in site selection, the designer and corrosion specialist must work with corporate planners. The latter use economic balances between transportation, marketing, raw materials and operating costs to locate facilities and plants within broad geographic areas. The relative costs from corrosion and material losses at various candidate sites may well affect estimated operating costs sufficiently to influence site selection. To date there has been little corrosion control input to these considerations.

The role of proper site selection in reducing corrosion can be better understood when comparative corrosion losses are considered. The corrosion of steel in the atmosphere, for example, can be 400 to 500 times as great on the seacoast as in the desert.⁽³⁾ Atmospheric differences are further accentuated by topographical, meteorological, air quality and use differences. Once recognized these factors can be used to reduce maintenance and operating problems from corrosion by judiciously placing plants where they have the least economic impact.

The effects of climate and geography on corrosion have long been recognized. Some organizations, such as the American Society for Testing and Materials (ASTM) and the British Iron and Steel Research Association (BISRA), have conducted programs over many years to determine and catalog the relative corrosion effects of different sites throughout the world.^(24,25) Newton and Makrides used eight general climatic conditions to predict world-wide atmospheric corrosion effects.⁽⁷⁾ Recently Rychterna and Nemcova⁽²⁶⁾ developed a world classification map to show the relative corrosion and degradation effects for various geographic regions. United States Weather Bureau fog maps, general rainfall information and seasonal precipitation data are also useful in making qualitative estimates of the relative corrosion behavior assessments. For example, the work of Thomas and Alderson⁽²⁷⁾ showed that higher corrosion losses were experienced than might have been expected from annual rainfall and temperature data in Northern California. Use of fog maps and seasonal precipitation data as shown in Figures 1 and 2 would have helped to anticipate that losses would be higher than those

FIGURE 1. Average Annual Number of Days of Dense Fog in California.

(Information taken from Reference 27)

FIGURE 2. Average Precipitation Data

experienced in New England and North Carolina where there are higher annual precipitation rates. In the latter two locations rainfall was sufficient in the summer to wash off most of the deposited salt from steel surfaces. In California moisture from fog and dew coupled with deposited salt accelerated the corrosion attack.

The information reported by Yocom^(28,29) on the effects of air pollution on corrosion and material degradation can be used by the designer and corrosion specialists. These adverse effects are caused by SO₂, CO₂, ozone, H₂S and moisture. In the late forties the U.S. economic loss from air pollution degradation effects was estimated to be 1-1/2 billion dollars. Fink and his coworkers reported that 1970 losses were \$1.45 billion.⁽³⁰⁾ Different assumptions were used in the two calculated values; however, the magnitude of the estimated costs are such that the importance of air pollution on corrosion is evident. Similar importance is attached to air pollution in England. Material losses in heavily industrialized areas were twice those encountered (as an average) elsewhere in that country.⁽²⁹⁾

Because industrial concentration and topographical and meteorological conditions differ, the air pollution effect varies throughout the world. Information is available, however, to help site plants avoid these problems if corrosion losses become a critical consideration in operating costs. Charts are available that give high pollution potential day forecasts for the U.S. ⁽³¹⁾ These show where high levels of air pollution can be expected over wide geographic regions because of stagnant high pressure centers. Such pressure centers tend to become stationary over California and the Appalachians. They can become unusually bothersome in the Los Angeles area, for example, where topographical features prevent the movement of air to the east and dispersion of air pollutants.

Moraru and Timar reported work in Romania on defining the severity of atmospheric corrosion near and along the Black Sea.⁽³²⁾ Zones with different corrosion rates were identified so that the construction of various facilities and buildings might be placed in areas where they would suffer less attack. Other studies with similar information for other locations throughout the world should be expected from time to time. The results of such studies should be used by designers and corporate planners when they are siting facilities as well as the conventional information mentioned earlier that is currently employed.

The interaction of meteorology and geography also has an important bearing on the relative severity of corrosion to the facilities located on tropical islands. Not only are there windward and leeward effects where the former is expected to result in more rainfall, but differences can also result from elevation.⁽³³⁾ The building located at the lower elevation can also idealized tropical situation shown in Figure 3 will probably have lower corrosion losses than the one located in the hills or mountains. It is assumed that the lower site is sufficiently distant from the sea that there are no sea borne spray effects as are discussed for shore or near-shore conditions in the next section. Generally speaking the low elevation site on the windward side would be expected to have a somewhat greater corrosion problem than would the leeward side example.

FIGURE 3. Effects of Prevailing Winds and Precipitation on the Location of Buildings.

In the continental United States, there are many types of aids available to help estimate the relative corrosivity of various geographic areas. These assessments should be made and input supplied in the decision making process on plant site selection so that corrosion losses can be reduced to a minimum.

LOCATION

Anti-corrosion design considerations relating to the location of equipment and facilities are similar to those found controlling corrosion in siting determinations. The geographic area of concern is limited, however, to specific locality variables or even to those encountered on a particular piece of property. In addition to the atmospheric variations that were discussed in the previous section, there are variations in soils that are of great importance. The corrosivity of the latter are related to pH, moisture, permeability to air and water, biological activity, composition and stray currents.

The importance of location in soils with a low corrosion potential can be illustrated by the two situations shown in Figure 4. A slight relocation of the pipeline to the preferred position would avoid a particularly bad area and at little or no extra cost. Parker⁽³⁴⁾ cites information on an actual case where the use of strict line-of-sight placement would have run the pipeline through several slush pits and one salt-water pit similar to those shown in Figure 4. In addition to the obvious advantages accruing to installation of the pipeline in the more desirable location, there is a much lower probability of future corrosion problems.

Distance from the sea is an important variable in reducing corrosion of equipment and facilities in coastal areas. Data from the atmospheric test facilities at Kure Beach, North Carolina, show that corrosion losses, on steel for example, are much higher 80 feet from the sea than they are at 800 feet from the sea. BISRA studies at Lagos, Apapa and Aro, Nigeria also found that corrosion decreases rapidly on moving inland.⁽²⁵⁾ Systems should, then, be placed as far from the sea as is feasible. The role of prevailing wind on facilities near the shore is shown in Figure 5. The structure near the windward beach will suffer greater corrosion than the downwind facility, which is equally as close to the shore but on the leeward side of the peninsula.⁽⁴⁾

The movement of airborne effluents is very complex and governed by the interaction of terrain, meteorological conditions and design of the effluent discharge source. Published information on the dispersal of these effluents^(29,31) can be used to advantage by the designer in locating facilities so that exposure to adverse conditions will be kept to a minimum. Of great importance in combating the potential corrosion effects of air pollution is knowledge of wind direction persistence. These data are commonly compiled to show the frequency at which wind blows in a given direction for a specified number of hours. The persistence data given in Table II are used in Figure 6 to show the most desirable and least desirable locations for placing a facility in the close proximity to a single stack source of air pollution. When

FIGURE 4. Effects of Buried Pipeline Location

FIGURE 5. Effects of Prevailing Wind and Salt Spray on Buildings Located Near the Shore

FIGURE 6. Effects of Wind Persistence on Plant Location

several buildings are to be constructed in a complex, the building that produces the corrosive fumes should be located downwind from the other buildings.⁽⁴⁾

TABLE II. Persistence of Wind Direction*

	N	NE	E	SE	S	SW	W	NW
6-12 hrs	24	26	5	47	54	78	79	38
13-24	1	5	0	16	16	24	28	11
25-36	0	2	0	0	3	0	6	1
37-42+	0	0	0	2	0	1	0	0

Note: The data indicates the number of separate instances in a single year during which the wind remained within the 45 deg sector indicated.

The deep river valley located shown in Figure 7 is an idealization of the air pollution problem encountered at Trail, British Columbia. Frequent meteorological inversions tend to hold the gaseous effluent close to the valley floor.⁽³⁵⁾ The possibilities for corrosion of facilities and equipment in this environment are much greater than those that would be encountered where the stack effluents were not so well contained. The designer should pay particular attention to the problems of effluent being essentially trapped or diverted by terrain, and place his facilities elsewhere to avoid the higher maintenance and operating costs that would be found under the conditions similar to those shown in Figure 7.

The possibility for corrosion attack is greater in sheltered areas where the relative humidity may be high and the sun and wind do not have the chance to remove condensed moisture from the metal.^(3,4,5) This can be avoided by placing buildings so that circulation is enhanced.

The designer frequently has considerable latitude in selecting a specific location within a comparatively narrow geographic region. He should follow Anderson's advice and look at structures in the area for clues on corrosion.⁽¹⁰⁾ It is hard to conceive of all of the conditions that might influence corrosion at a specific location so use of existing information provided by adjacent or nearby facilities is a very useful method for validating assumptions and providing additional input. With this local data and a knowledge of the effects of climate, terrain and corrosive atmospheres on materials, the design can play an important role in reducing maintenance and operating costs.

*Taken from Reference 31.

FIGURE 7. Effects of Inversions of Flow on Stack Effluent in Deep Valleys

LAYOUT

A major consideration in the layout of facilities and equipment is to provide for the most economic relative location of the various items involved in the process. Frequently these determinations have been made without input from personnel concerned with corrosion and its subsequent influence on maintenance and operating costs. To reduce corrosion by proper layout, the designer becomes concerned with accessibility, relative orientation, and relative position of the various items in the process.

The importance of relative position effects in the layout of systems is shown in Figure 8. If both stacks discharge essentially the same effluents they should be of the same height even though one may carry a much larger volume of effluent material. The discharge of fumes from one stack against the side of another can lead to severe corrosion.⁽¹⁴⁾ Even in the desired position, plume problems can be encountered under certain meteorological conditions for two closely situated stacks that have "downwash" or "creep" of the effluent down the stack. However, for well-designed stacks, the exposure to these undesirable conditions will be minimal, and equal stack heights will reduce the overall amount of attack.

System layout should be done so that liquids are not held in pockets created by the design.^(11,23) Drainage should be arranged to discharge clear of all steelwork. Poor layout support structures on process equipment as Kaess notes can lead to reorientation of platforms, structural member overlapping and water holdup problems.⁽³⁶⁾

The need for proper access manifests in several different ways. Cleanliness, for example, is an important variable in reducing corrosion. Operators and maintenance personnel must be able to reach equipment to remove spillage, grime, etc. Further to the point, operators and service personnel will only clean a system or plant routinely if it is easy to clean.⁽⁹⁾ The designer has the added charge of making it easy - not just feasible or possible to clean - for corrosion prevention benefits to accrue.

In the food industry uncluttered process rooms, (a function of good layout design) are needed, according to Guthrie, for clean operation.⁽²¹⁾ Such designs prevent: a) insect and rodent attraction, b) accumulation of wastes, c) corrosion damage to equipment, d) contamination of successive process lots and e) simplifies and increases efficiency of disinfection.

Koger and Roebuck have described systems that have been constructed with specifications calling for the application of protective coatings.^(37,38) In one case it was the supporting structure for a shipboard helicopter landing pad, and in the other, a large container. The supporting structure consisted of a maze of interlacing structural steel, and the latter had a single, very small opening. In neither case could specifications be met; it was impossible to apply the coating because the designer had not provided access for personnel and their equipment to completely prepare the surfaces and apply the protective coatings.

FIGURE 8. Effects of Stack Height

Many segments of industry are now using modern operations management techniques in the layout of process and product oriented production systems. Depending on the complexity of the layout problem, either graphic or computerized procedures are used to provide the most economical relative layout of the process. These have been described by Buffa⁽³⁹⁾ and are amenable to anti-corrosion design inputs. Relative corrosion costs for different candidate layouts must be estimated and fed into the calculational process so that the best overall economic balance may be obtained. Those interested in anti-corrosion design would be remiss in not recognizing the use of advanced techniques such as this, and applying appropriate costs to provide for ease in cleaning and reduced corrosion so that proper restraints are computed into the layout models.

STRUCTURALS

Tees, channels, angles, "I" beams, square beams, rectangular beams and tubular beams are used to carry structural loads and give shape to facilities and plant systems. Because of configuration, certain of these structurals are most susceptible to corrosion than others. Figure 9 shows the more desirable shapes from an anti-corrosion standpoint. The most desirable are those that will not catch and hold solutions and dirt. Where those structurals such as tees, angles, channels, etc. are used that can retain solutions or dirt, care should be used to orient them so that retaining edges are pointed down as in Figure 9.^(5,11,40)

As another consideration for the designer, box, rectangular and tubular beams cost less for equivalent strength capacity and also to sand blast and paint. With sand blasting alone costing \$0.25/ft² reducing the amount of surface area requiring such treatment and subsequent coating becomes an important consideration. Box, rectangular and tubular beams also have the fewest surfaces and the smallest number of possibilities for "edge effect" coating flow. This effect is shown in Figure 10. (the example was taken from reference (42)). The tubular beam is ideal since there are no edges. When these hollow members are used, if possible, they should be completely sealed from the atmosphere so as to prevent the accumulation or retention of moisture on their interior surfaces.

JOINING

The common joining procedures are welding, bolting, riveting, and use of screwed connections. These are a source of concern because they frequently provide crevice or stress areas that establish anodic-cathodic cells. Another major corrosion problem arises from joining dissimilar materials that create galvanic cells. Landrum has identified crevice corrosion effects as the most prevalent cause of equipment failure, so care should be exercised to avoid this problem in joining materials.⁽⁴⁰⁾ These crevices become cells when they are filled with solutions that have concentrations or temperatures that are different from bulk process conditions. LaRocca has pointed out that crevices are sites for microbiological activity⁽²³⁾ and Guthrie that they create unsanitary conditions in the food industry.⁽²¹⁾

FIGURE 9. Structural Member Effects

FIGURE 10. Edge Effects and Coatings

Figure 11 shows good and poor welding practice for joining support plates. Continuous welds on both sides, although more expensive, avoid the crevices created by skip welding. The latter may be a more economical fabrication technique, but maintenance costs can easily offset this initial advantage in any corrosive environment. Full penetration welds as shown in the "good practice" case in Figure 11 avoid the creation of a large crevice area if pinhole leaks develop. The problems associated with riveted joints, bolted connections and lap welds are shown in Figure 12. The use of insulation can reduce the amount of trouble encountered with some of these joining methods. (12,17,40)

Chandler and his coworkers have identified procedures for avoiding problems when steel contacts absorbent materials or steel is embedded in concrete. (42) The recommended method for avoiding difficulties as well as the undesirable approach for the case of a wood-steel interface are shown in Figure 13. Wood, in addition to being an absorbent that will hold water in contact with the steel, also emits vapors and secretions that may accelerate corrosion of the steel. Use of a filler and a good protective coating for the wood as well as the steel will reduce problems of this nature. When steel is embedded in concrete care should be exercised to avoid a crevice at the steel-concrete interface. Good and poor practice conditions for this situation are shown in Figure 14.

VESSELS

Vessels are an integral part of the process industry and transportation systems. They are also frequently designed so that the possibilities of having corrosion problems are enhanced rather than avoided. In Figure 15 common techniques for removing liquids are shown. The discharge line should be located so that the vessel may be completely drained; otherwise, sludges or solutions of different concentration can accumulate. These could cause galvanic corrosion. If drainout valves or plugs are used their upper edge should be flushed with the interior surface of the tank bottom. (13) The heel left after draining in the "poor" design cases would also lead to preferential attack problems. Similar difficulties could be encountered if baffles and diverters were not located correctly and designed to allow complete drainage.

The dairy and food processing industries frequently uses vessels with discharge ports on the bottom but located at one side of the tank. These systems too must be designed to ensure complete drainage. (43) Because many of these vessels are rectangular in shape the corners are rounded to reduce solution holdup and to ease cleaning. (44)

Figure 16 shows good, fair, and poor practice procedures for use of concrete supporting pedestals. Use of a continuously welded collar supported by a metal saddle adjacent to the concrete will reduce corrosion from spillage. Use of only the welded collar adjacent to the concrete support may be acceptable if the expected service life of the tank is comparatively low or the environment is not overly aggressive. Direct contact between the metal tank and the concrete offers a potentially serious maintenance problem where an

FIGURE 11. Joining Practices

FIGURE 12. Welding and Riveting Practice

FIGURE 13. Effects of Contacting Steel
With Absorbent Materials

FIGURE 14. Effects of Steel Embedded in Concrete

FIGURE 15. Tank Drainage

FIGURE 16. Concrete Tank Supports

opportunity exists for spills or frequent exposures to corrosive sprays or mists. For tanks with the long axis vertical, frequently a crowned concrete pad is used to avoid problems. Additional protection can be obtained by having an additional layer of steel attached with a continuous weld to the bottom of the tank as shown in Figure 17. In supporting large flat bottomed tanks, however, it is generally better practice to design so that free air circulation is permitted rather than partially seal off the bottom surfaces where moisture and chemical solutions could accumulate.⁽⁵⁾

PIPING

Piping is an ever-present part of industry. It is used to transport fluids and slurries of different corrosivities through industrial, rural and marine environments, and through different soils, all of which have different corrosion effects. The general tenets of anti-corrosion design that reduce the possibility for corrosion in these cases are shown in Figure 18. Impingement and turbulence should be avoided wherever possible. There are also occasions when very low flow rates cause trouble.⁽¹⁷⁾ Settling may occur from solutions having high solids content with resulting deposits on the bottom of the pipe. Higher corrosion rates should be expected under these deposits. Deadlegs or stagnant flow regions are also undesirable. Instrument sensing lines, for example, should enter from the top of a pipe rather than from the bottom. The latter situation creates a deadleg that may lead to severe corrosion in aggressive solution environments. A similar problem may occur if valves are placed on a vertical run of piping.⁽⁴⁵⁾ A better location is on a horizontal run. Avoidance of deadlegs becomes even more important in those systems where chemical cleaning may be necessary.⁽⁵⁾ All systems designed for in-place cleaning must be self-draining.^(21,43) Loucks⁽⁴⁶⁾ and Perrigo⁽⁴⁷⁾ have described the problems that can be encountered if solutions cannot be readily introduced and removed. One of the most frequently encountered sources of deadlegs is the mismatching of process area lines with their continuations in yard banks.⁽³⁶⁾ This not only involves dimensional errors but leads to unnecessary twists and turns on one side of a match line to meet a point on the other side.

Interfaces between air and liquids are frequently the site of corrosion attack.⁽⁵⁾ The vapor pocket shown in Figure 19 may be avoided by suitable use of vent lines. Piping runs should be sloped for easy draining. Most piping corrosion problems can be minimized by proper arrangement or orientation; these factors are completely controlled by the design engineer.

Burton and Landrum have described examples of how uneven heat transfer in flues can lead to severe corrosion.^(13,40) The supporting members in Figure 20 act as cooling fins if they are not properly insulated. The localized cold spot can drop the temperature below the dew point causing condensation. Sulfur oxides in the flue gases will produce dilute sulfuric and sulfurous acids which will accentuate the condensate attack on mild steel surfaces.

FIGURE 17. Tank Supports

FIGURE 18. Piping Design

FIGURE 19. Vapor Pocket Effects

FIGURE 20. Effects of Insulation

FLOORS

In this discussion, floors are defined as all industrial structures where people walk. This includes concrete slabs, tile, acid brick, wood decking and grating.

Industrial floors, especially those exposed to corrosive spillages, frequently receive less design study than any other part of the building process.⁽⁴⁸⁾ The consequences of inattention can be serious. Production may be lost, the stability of structures compromised and hazards to attendant personnel created. An easy and inexpensive method for reducing floor attack is to slope all floors and provide sufficient floor drains.⁽⁹⁾ Care must be exercised to avoid uneven areas that will holdup liquids.⁽⁴⁹⁾ Monolithic concrete has advantages in certain systems, while floors with sacrificial tile may be the most useful solution to spill damage in others. Metal decking with isolated skid-resistant protrusions is much more desirable than interlocking diamond or ring varieties.⁽¹⁴⁾ The latter retain solutions which enhance corrosion of the surfaces.

Figure 21 shows six designs of commonly used industrial gratings. These are classified in this presentation according to their design features for avoiding or promoting the possibilities for corrosion. The welded grating variety shown in Figure 21 contains no crevices or solution holdup areas. In its desirable form the perforated plate grating has similar attributes. Care should be exercised in selection of this variety to avoid those produced by punching processes that cup the metal enough to retain solutions at various places on the surface. The ridged-mechanical joined, the interlocking key, riveted and interlocking joint varieties all have crevices and some holdup areas. They should not be used in corrosive atmospheres.

PROCESS CONDITIONS

During the selection of process conditions much can be done to avoid or control corrosion after the equipment is constructed and in operation. Small changes made in temperature or flow, methods for introducing or removing liquids and handling transient operation can avoid or control corrosion in process systems. Frequently these changes can be effected without a loss in process efficiency.

Maintaining temperature about the dewpoint in gaseous systems having chlorine, chlorine derivative and acid forming gases such as NO_2 , SO_2 and SO_3 is very important.⁽⁵⁰⁾ The formation of aqueous condensates can lead to catastrophic corrosion problems. The SO_2/SO_3 problem is relevant throughout all sectors of industry. Boilers or process heaters may be subjected to attack anywhere the metal surface is cool enough to permit condensation of sulfuric acid.⁽¹⁷⁾ An increase in SO_3 from 1 to 5 ppm can raise the dewpoint of flue gas by over 500°F.⁽⁵⁰⁾

FIGURE 21. Effects of Grating Design on Corrosion

The position where concentrated or high-temperature solutions are introduced into process vessels has an important effect on corrosion. If entry is made at the center of the vessel concentration cell corrosion problems are avoided.⁽¹²⁾

REMEDIES

Because corrosion control design procedures have not been widely used in many industries, many poor designs have been placed in service. Frequently, however, there are opportunities for remedial action where some or all of the undesirable effects of these unfortunate situations can be avoided at a minor cost. Figure 22 shows how corrosion of tank support members resulting from spillages may be minimized.⁽⁴⁰⁾ Sheet metal may be joined by a continuous weld to the tank to act as a drip skirt. Protection may be given to structural members by drilling holes in the webbing at frequent intervals as shown in Figure 23.^(5,40) Also, packing and protective coatings may be usefully employed to cover crevice and holdup areas. Care must be exercised to ensure that the crevices and holdup areas are thoroughly covered, however, or more serious problems could result. Many hot spot corrosion problems can be avoided by rearranging the location of the heaters with respect to vessel walls or avoiding direct flame impingement.⁽⁴⁰⁾ Cold spot heat transfer-induced corrosion problems may be avoided by adding insulation to tanks and piping systems. Vents may be installed on most piping circuits at a minimum cost to prevent corrosion at liquid-vapor interfaces. The most economical remedy may be frequent replacement with common and relatively inexpensive materials.⁽⁵¹⁾

These examples show how easily certain poor design problems may be overcome. Other solutions probably exist, which have not been recorded. There are many other situations, however, where remedial action is excessively expensive and no feasible action is possible.

DIFFERENT SYSTEM REQUIREMENTS

The corrosion control design procedures that have been presented in the previous sections do not constitute an absolute philosophy to be followed without thought. Different needs and different systems create a need for different approaches to the problem of how to design to avoid corrosion.

The need for large surface areas to promote more efficient heat and mass transfer also produces conflicts. Turbulent rather than laminar conditions are preferred and these can result in higher corrosion. Drainage and cleaning problems can be expected. The economics of operation must be balanced to produce the best design under these conditions.

Seiberling cautions against use of vertical deadends in the food industry because trapped air prevents cleaning solutions from reaching the upper portion of the fitting, and thoroughly removing any microbiological contamination.⁽⁴⁴⁾ Other process industries encourage locating instrument lines from the top of lines which are essentially deadlegs because this promotes better drainage and prevent cleaning solution holdup.

FIGURE 22. Tank Support and Protection

FIGURE 23. Protection for Structural Members

SUMMARY AND CONCLUSIONS

By applying simple and straightforward principles to the design of systems, buildings and equipment, operational corrosion problems may be reduced or avoided. These corrosion control design principles are concerned with promoting the use of orientation, layout, and configuration to avoid the holdup of solutions, abrupt flow changes, impingement and stagnant areas. Climatic conditions and terrain are important siting considerations in reducing atmospheric corrosion of buildings and facilities. A determined effort is needed to broaden the understanding of anti-corrosion design measures and principles because these are not widely known and recognized by designers and architects.

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