

VALUE-FOR-MONEY CORROSION ENGINEERING

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ABSTRACT

The consequences of corrosion are often very costly. Little surprise, therefore, that a substantial engineering effort is directed at its prevention or control. By contrast, comparatively little consideration seems to be directed towards making that anticorrosion effort cost effective. This paper addresses the problem of ensuring value-for-money corrosion engineering. The first step is a corrosion risk assessment to rank the consequences of all predicted failures. This enables the overall strategy of dealing with corrosion to be set. Such a strategy might involve corrosion prevention, or life-time corrosion control for items determined to be at high risk. It might also involve less rigorous (but monitored) protection for items judged to fall into the medium risk category, and possibly no action in respect of low risk items. The various corrosion engineering options (viz. do nothing, design, materials selection, coating, cathodic protection, inhibition) are then technically and economically evaluated for each item of plant as are the related corrosion evaluation activities (surveying, testing, inspection, monitoring). This enables a corrosion management plan to be established.

KEYWORDS

Corrosion risk assessment, corrosion management, monitoring, data management, economic analysis.

INTRODUCTION

An old popular song says "rust never sleeps"; a truism reflecting the fact that corrosion is ever present, relentlessly eating away at the economic fabric of society. So much of what we take for granted in modern life: the processed food we eat, the electricity that flows when we throw a switch, water at the turn of a tap, fuels and lubricants for our vehicles, indeed practically any substance or component we use, all have been produced by an industry in an on-going conflict with corrosion. Inevitably, the costs of that conflict are passed on to the consumer. Corrosion makes us all poorer.

How much poorer will never be accurately known. By way of approximation a number of studies conducted since the early 1970's (1-3) have arrived at the consensus that corrosion accounts for around 3-4% of the gross domestic product of a developed country. Much of that cost is encountered in the primary producing industries such as petroleum and petrochemicals. In these industries, therefore, it is little surprise that the growing awareness of the costs of corrosion instils a desire for more effort and expenditure on corrosion prevention and control: a desire actively encouraged by purveyors of anticorrosion materials and systems.

But is the expenditure necessary?

The accountant can usually produce figures to describe the impact of a corrosion failure on the profitability of an enterprise. Some of the tangible, and not so tangible, components of the calculation are listed in Table 1. By contrast, the accountant is rarely moved to make an assessment of the cost of not having a failure. If plant and equipment operates without

breaking down we are usually satisfied. It is rare to question whether the cost involved in achieving this absence of failure is excessive or has been worthwhile. Table 2 lists some sources of possible over-spending in endeavouring to avoid corrosion failures.

TABLE 1 - SOME COSTS OF CORROSION FAILURE

♦ safety hazards	♦ pollution clean-up costs
♦ loss of capital plant or equipment	♦ increased insurance premiums
♦ fire/explosion	♦ loss of consumer confidence
♦ loss of production capacity	♦ alienation of workforce
♦ loss of product quality	♦ increased scrutiny by statutory bodies
♦ maintenance/repair/replacement	♦ public image
♦ loss of stored/entrained product	♦

TABLE 2 - SOME COSTS OF OVER-PROTECTION

♦ unnecessarily expensive materials	♦ excessive data handling
♦ overdesign of metal sections	♦ overdesigned CP systems
♦ excessive weight	♦ over-operated CP systems
♦ excessive inhibitor consumption	♦ excessive replacement stocks
♦ excessive monitoring	♦ premature retirement of equipment
♦ excessive inspection	♦ over specified protective coatings

Thus, while corrosion is inevitable, it should neither proceed unchecked nor should it be prevented at all costs. The sound engineering approach requires corrosion controlling resources to be applied in a manner commensurate with the costs of the corrosion failures that we are trying to avoid. Never spend more on corrosion control than is worth spending to avoid the consequences of failure. In other words, we seek value-for-money corrosion engineering. To achieve this requires first that we conduct a *corrosion risk assessment* to quantify the consequences of all predicted failures. The results of the assessment enable the overall strategy of dealing with corrosion to be developed logically and implemented in an orderly way through a *corrosion management programme*.

CORROSION RISK ASSESSMENT

The methodology of conducting a corrosion risk assessment (CRA) has been discussed in detail elsewhere (4) and only a brief outline is presented here.

In executing a corrosion risk assessment it is axiomatic that corrosion does not matter but its consequences do. The assessment synthesises objective corrosion engineering estimates of the possibility of corrosion failures with the operating company's subjective view of the level of undesirability of each such failure.

There are four stages in conducting the assessment:

Assigning a Life Factor (L)

The residual corrosion life of any component is the time required for corrosion at the predicted rate to lead to failure to perform the designed mechanical duty. Given information on the materials of construction, the exposure environment and the relevant circumstances (e.g. temperature, pressure, flow, heat transfer, stress) the morphology of corrosion can be predicted with confidence. Where uniform attack is expected, maximum penetration rates can be calculated using conventional corrosion engineering practice, for example, public domain algorithms (5-8) supplemented by in-house database information. If localized corrosion (e.g. pitting attack or one of the corrosion cracking modes of failure) is predicted, probabilistic analyses of failure are more useful (9).

For risk assessment purposes the estimate of residual life (in years) is usually transposed to a dimensionless Life Factor (L), reflecting short, medium or long life expectations.

Assigning Consequence Factors (C)

The consequence factor (C) expresses the relative undesirability of all the perceived consequences of a corrosion failure. This is arrived at by structured interviews with plant management, operations personnel, maintenance engineers, loss prevention officers etc. Although it incorporates subjective assessments, and opinions, the methodology of analysis is rigorous and the rankings produced accurately reflect in a quantitative way the operating aspirations of the company.

There are two elements in C:

- ♦ the individual consequence (e.g. safety, loss of production etc.). Some consequences are regarded by the company as more undesirable than others, to the extent that staff can develop a points loading to be applied to each. This gives a Consequence Rating (F), a typical set of which is given in Table 3

and

- ♦ the event that may lead to that consequence, represented by an Event Rating (P). Manifestly, a number of unique events might occur all giving rise to a particular consequence. These events, too, may be loaded in a points system to reflect their perceived undesirability, as shown for example in Table 4.

TABLE 3 - TYPICAL CONSEQUENCE RATINGS (F)

Consequence	Consequence Rating
risk of safety to personnel	10
loss of production	9
pollution	3
loss of product quality	1
loss of consumer confidence	1

TABLE 4 - EVENT RATINGS FOR TWO PLANTS IN A SEQUENTIAL TRAIN

Consequence	Event	Event Rating (P)
Safety	Crack in a toxic line or equipment	10
	Pinhole in a melt line	10
	Crack in a flammable line or equipment	9
	Crack in other HP line or equipment	7
	Pinhole in a flammable line or equipment	7
	Pinhole in other HP line or equipment	6
	Other cracks	5
	Pinhole in toxic line or equipment	4
	Other leaks	2
	Falling objects	1
Outage	In plant no. 1 - no standby	10
	In plant no. 2 (HP) - no standby	9
	In plant no. 2 (LP) - no standby	7
	In plant no. 1 - standby	5
	In plant no. 1 - non-critical - no standby	5
	In plant no. 2 - standby	4
	In plant no. 2 - non-critical	3
	In plant no. 1 - non-critical - standby	3
Pollution	Marine	10
	Atmospheric	5
Quality	Final product (colour only)	10
	Intermediate product	5

The two elements of C are combined in the manner:

$$C = \int C_x = \int f_n (F_x, P_x) \quad [1]$$

where the subscript x refers to the sequential analysis of the various consequences e.g. safety, outage, pollution and product quality. The shape of the function linking the event and consequence ratings is determined by a formalized heuristic procedure. The function is modified through a series of computer iterations, with the effect on the value of risk (see below) being assessed after each run.

The Risk Equation

The risk equation must reflect the perception of risk associated with various forms and rates of failure, as viewed by the operating company. At its simplest level the equation produces a numerical assessment of risk, R , of the general form:

$$R = f_n(L, C) \quad [2]$$

Allocation of Risk Classes

The value of R provides a numerical assessment of the corrosion risk: the higher the R value for an item the more attention that must be focussed on its corrosion situation.

In practice the spread of numerical risk values within a facility usually prove to be discontinuous. That is the risk numbers tend to fall in groups with distinctive breaks between. This usually permits a convenient reduction of the numeric data into risk classes (e.g. low, medium and high). Such sub-division aids communication of the outcome of the risk analysis on a narrative basis and in colour coded risk diagrams.

CORROSION MANAGEMENT PROGRAMMES

Corrosion risk assessment is not an end in itself. Its role is to provide the evidence that will permit the construction of a cost-effective corrosion management programme. The objectives of a corrosion management programme may be stated as:

- ♦ to maintain corrosion control within pre-determined *acceptable limits* and at *minimum cost*
- ♦ to facilitate rapid access to records showing the corrosion status of the facility in order to provide assurance for managers, owners and statutory bodies
- ♦ to ensure that corrosion upsets are speedily identified and that the appropriate remedial action is presented, so bringing the combined benefits of safety, economy and environmental security.

Fulfilling these objectives is a unique exercise for every different facility: petroleum production, refinery, chemical processing, steam generation, nuclear installation etc. However, the philosophy of the approach is common to all. First an overall strategy for corrosion management must be agreed upon and then, when this is established, the "tactics" become largely self-evident.

Strategic Considerations

The corrosion risk assessment will have produced a risk ranking for all components of the plant under consideration. This will enable a strategy for corrosion management to be set down. Table 5 illustrates a strategy that might be drawn up for an industrial facility. The actual strategy selected will depend upon the particular facility under study.

TABLE 5 - CORROSION MANAGEMENT STRATEGY

Assessed Risk		Corrosion Management Options
High	1) 2) 3)	corrosion prevention corrosion control for facility life corrosion control for economic planned maintenance on replacement
Medium	1) 2)	corrosion control for facility life planned maintenance
Low	1)	no action, replace if required

It will be noted that corrosion prevention, or assiduous corrosion control, is dictated by a high risk classification, whereas low risk permits, quite legitimately, inactivity in so far as corrosion control is concerned. A medium risk classification will inevitably call for a degree of corrosion management that is intermediate between the high and low risk cases. Thus, corrosion management may involve taking action or taking no action as the circumstances require. However, taking action or taking no action is not corrosion management unless the decision to adopt either has been based on an analysis of the acceptability of the consequences of failure.

Having determined the strategy, the relevant corrosion options can be considered for every individual item in relation to the engineering and operational constraints of the facility. In other words, the tactics can be decided upon.

Tactical Considerations

Corrosion *prevention*, that is complete elimination of the chance of corrosion failure is rarely possible. Invariably it would require a significant engineering change impacting adversely on the capital cost of the project. Examples would include investment in corrosion resistant alloys for plant construction, or modifications to the process (e.g. crude gas dehydration) to render the fluids benign. Of course, neither would be welcome suggestions in the case of a plant that was up and running. Even with a new plant such proposals might raise major design and engineering problems.

It is much more likely that active corrosion *control* will be introduced with the object of extending the time to failure of a component to a value in excess of the life of the plant, or to some economically viable planned maintenance or replacement interval. The adoption of this tactic requires that:

- ◊ the performance targets of the corrosion control are defined
- ◊ procedures are set in place for ensuring that these performance targets are met

The performance target may be set, for example, in terms of an allowable rate of corrosion penetration. Alternatively, limits may be set on some parameter that is an indicator of the propensity for corrosion. Such parameters may be the potential in anodic or cathodic protection systems, the level of dissolved oxygen in oilfield water injection or boiler feed

systems, pH, temperature, dewpoint etc. Irrespective of which approach is used it will be necessary to obtain on-line information on the behaviour of the corrosion controlling system and to use that information to make adjustments as required. Thus corrosion monitoring and inspection is necessary, and it then forms an integral part of the corrosion management. Table 6 lists some monitoring functions and indicates how they are related to corrosion control.

TABLE 6 - CORROSION MONITORING AND CORROSION CONTROL

Example of Corrosion Control Method	Typical Monitoring Techniques	Examples of Adjustments Based on Monitoring Data
inhibition of crude oil pipelines	on-line probes (eg. coupons, electrical resistance probes)	adjust inhibitor dosage change inhibitor type discontinue inhibition
de-oxygenation of boiler feed-water	O ₂ probes chemical analysis	adjust oxygen scavenger add inhibitor check pump seals etc.
impressed current CP	measure potential	adjust CP system output
anodic protection of sulphuric acid plant	measure potential	adjust AP system output
dehydration of process gas	on-line probes moisture detection	temporary inhibition overhaul dehydrator

It is the efficient gathering and processing of relevant information, and its judicious application in making on-going adjustments to corrosion control, that is the key to an effective corrosion management programme.

Policing the system

In any facility the means of corrosion management will vary from place to place. In one location a corrosion resistant alloy may be used, in another cathodic protection allied to coating may be employed, whilst elsewhere no action may be taken because the consequences of any failure are regarded as unimportant. In short, no corrosion management action is taken that does not contribute positively to meeting the objectives of management, and the level of action is the minimum that is necessary. An essential part of a corrosion management plan is the means of assessing performance. This is achieved by monitoring and inspection.

Monitoring requires the use of fixed sensors to follow what is occurring at that point. The sensors may detect and measure corrosion, they may alternatively detect species that can lead to corrosion (dissolved oxygen, for example) or detect species produced by corrosion (metal ions or corrosion product fouling). Whilst the sensors should be located at points where the corrosion control is thought to be least effective, it is desirable to check that corrosion is equally under control elsewhere. By using NDT inspection techniques at regular intervals at identified key points in the plant, not only can the monitoring data be validated, but a

quantitative readout of the progress of corrosion with time can be achieved. This will confirm whether or not the target corrosion rates are being met.

There is no merit in policing the system if no action is taken after consideration of the results obtained: policing implies action! It follows that there is no value in monitoring a point where no adjustment to the corrosion management is possible e.g. upstream of an inhibitor injector. The only valid exception would be where there was evidence of a potential problem. Monitoring might then usefully be adopted to check; provided it was intended to introduce some method of corrosion management if the problem was confirmed.

The data that are produced from the policing activities must be valid (requiring careful calibration) and limited in volume so as not to deter analysis or hide anomalies. Thus it is important to restrict monitoring points and key points to critical positions and to limit the frequency of inspection and survey work. In the case of the latter, the time to the next inspection or survey should be clearly indicated by the results of the current work. That is, a fixed interval programme will usually prove wasteful; inspection and survey work should be on an as-needs basis.

Reviewing the corrosion management activities

This paper has in fact dealt with corrosion management programmes although the phrase has been used sparingly. The risk assessment represents the first stage in developing such a programme for a facility. The corrosion management strategy derives directly from it and acts as the template for selecting and applying the tactics of corrosion control and putting in place the necessary monitoring and inspection programmes.

From time to time a corrosion management programme should be reviewed at both the strategic and tactical level. In human affairs things change. The management of a facility will always be alive to current market trends, competitors activities, interest rate movements and so on. Inevitably it may be necessary to revise the management objectives from time to time. Since the corrosion management programme was constructed to meet the earlier objectives it will be necessary to review the programme and possibly to alter it. Likewise, the pace of technological change is rapid compared to the anticipated lifetime of most facilities. Thus new, more effective and cheaper means of achieving the same ends may emerge and, indeed, it may be possible to adopt them in place of existing tactics within the corrosion management programme. Thus the programme is not a fixed blueprint, but a means to an end that must be reviewed and revised to meet the current management objectives.

EXAMPLES

Two recent examples illustrate how a CRA provided important results for the clients. In the first instance the CRA of a petrochemical complex in the Middle East found the plant to be extremely well engineered from the corrosion standpoint. It was constructed predominantly in carbon steel, with excursions into more exotic metallurgy only where the process conditions demanded it. However, the CRA highlighted, somewhat to the client's surprise, the cooling water system as a high risk area.

By using a closed system with secondary cooling by seawater and specifying high quality water and corrosion inhibitors, the designers had judged that it was possible to construct the majority of the cooling system in carbon steel. Certain of the primary heat exchangers were, however, constructed in stainless steel due to the aggressivity of the process fluid. The CRA identified modes whereby the quality of the cooling water could be adversely affected (e.g. by leakage of seawater and secondary plate exchangers). Failure to maintain cooling water

within specification would very rapidly lead to stress corrosion cracking of one of ten critical stainless steel process exchangers, failure of any one of which would halt production.

In view of this, Global Corrosion put forward recommendations for modest on-line monitoring of cooling water quality. Tied to this was the setting up of a formal action plan to be followed in the event a sudden deterioration in water quality should be detected. The client accepted and implemented these recommendations but, unfortunately, not before one failure of the type predicted occurred.

The second example derives from an installation, also in the Middle East. The CRA concluded that the absence of cathodic protection (CP) on water storage tanks, together with the prevailing soil conditions, would result in high corrosion rates. Since an adequate supply of water was essential to maintain production, the CRA concluded that the prospective failure of such tanks constituted a high risk and it was strongly recommended that CP be installed.

In the event the client was reluctant to accept and act upon the outcome of the report. Just under a year later the raw water tank perforated due to soil-side corrosion. The resulting loss of water caused a two week interruption in production, prompted a belated decision to install CP and engendered in the client a heightened appreciation of the benefits of corrosion risk assessment and the need for corrosion management.

SUMMARY

Corrosion cannot be ignored for it will not go away. However, there is as little merit in controlling corrosion simply because it occurs as there is in taking no action to prevent it unless the consequences of failure have first been considered. Good corrosion management aims to maintain, at minimum cost, the levels of corrosion within pre-determined acceptable limits. This requires that corrosion controlling measures are introduced and their effectiveness ensured by a judicious, and not excessive, programme of on-going corrosion monitoring and inspection.

REFERENCES

- 1) T.P. Hoar (Chairman), *Report of the Committee on Corrosion and Protection* HMSO (London, UK) 1971
- 2) L.H. Bennett et. al., *National Bureau of Standards Special Publication 511.1* NBS (Washington, USA) 1978
- 3) B.W. Cherry and B.S. Skerry, *Corrosion in Australia* Monash University (Clayton, Australia) 1983
- 4) V. Ashworth and W.R. Jacob, *Proc. IEF Meeting* (Tripoli, Libya) 1991
- 5) C. de Waard, V. Lotz and D.E. Milliams, *Corrosion* **47**, 976 (1991)
- 6) F.A. Posey and A.A. Palko, *Corrosion* **35**, 38 (1979)
- 7) A.H. Tuthill, *Materials Performance* **26**, (9) 12 (1987)
- 8) J.W. Oldfield, G.L. Swales and B. Todd, *Proc 2nd BSE/NACE Corrosion Conf.* Bahrain (1981)
- 9) M. Akashi, *Proc. Conf. Life Prediction of Corrodible Structures*, Cambridge (1991)