TRENDS IN MODERN CORROSION MANAGEMENT AND ON-LINE PLANT HEALTH ASSESSMENT

William M. Cox
Corrosion Management (UK) Ltd.
Meherwan P. Boyce
The Boyce Consultancy, Houston, USA
&
Masazumi Miyazawa and Yutaka Tanaka
Mitsubishi Chemical Corporation, Japan

ABSTRACT

A revolution is taking place in plant health assessment. The combination of condition monitoring techniques with modern data handling systems and risk-informed operating and maintenance strategies enable cost savings to be achieved that cannot be matched by conventional engineering approaches. Modern on-line corrosion assessment can be used to provide an indication of the condition of static equipment. Examples are drawn from corrosion appraisal in condensing systems (dewpoint corrosion), chemical process streams and high temperature applications. Combining these on line corrosion techniques with the on-line machinery monitoring systems, creates a total plant condition management system. The paper examines the separate but complementary roles of instrumentation and inspection and considers how their effectiveness can be maximised in modern process plant installations.

1. Introduction

Traditional corrosion control and condition monitoring are considered to be a support service activity. There are several reasons why this is so: perhaps in part it was a result of the people involved being mainly technical specialists and ‘enthusiasts’ who did not have production responsibility and accountability. Perhaps also the techniques used were not fully refined.

The basic techniques of corrosion and condition monitoring have been refined, new technologies have been added, and their functionality has been augmented by the application of modern computerised data collection, evaluation and presentation. These developments have delivered the capability of real-time prediction of equipment condition. As yet, however, their power to reduce operating and maintenance costs on large process plants has not been fully realised.

Nevertheless, modern techniques of plant health management are being taken up by an increasingly broad spectrum of the major process industries. Arguably, the petrochemical processing industry is leading the way, but the oil and gas production, refining and chemical, electric power generation, nuclear and aerospace industries are also introducing modern plant health management technologies at an ever-increasing rate.

It is the purpose of the present paper to track how the capabilities have developed, clarify where they fit in modern plant management and provide a strategy by which to obtain their most effective application.

2. Corrosion Monitoring

In the past, corrosion control tended to be an off-line activity covering materials and coatings selection, failure investigation and inspection. The costs of corrosion damage were hidden in maintenance replacements. This has meant that the true cost of corrosion attack went unrecognised in all but a few perceptive organisations where individual corrosion engineers with flair and presence were able to impress upon their colleagues the need for more attention to corrosion control. Still, the tools to achieve better control were limited and in consequence, the ability of the corrosion engineer to make a significant impact on day-to-day practices was similarly limited.

One area where on-line methods were more common was in the selling of corrosion inhibitors. Chemical treatment vendors were the first people to use basic corrosion monitoring instrumentation as a way to demonstrate the relative effectiveness of their products in the oil and gas production and water treatment industries and to promote their products. Baker Chemical led the way with early electrical resistance (ER) instrumentation, and the then rival Petrolite organisation pioneered the field use of electrochemical polarisation (LPR) methods. Rarely, however, was corrosion monitoring used as the means of controlling inhibitor dose rate, the service companies relying primarily on analyses of system chemistry to control the dosing programmes. Nevertheless, this type of application constituted the earliest attempt to achieve extended plant service life by the use of corrosion monitoring instrumentation.

In recent years it was recognised that corrosion is, in fact, the **number one life-limiting plant degradation mechanism**. The cost implications of this are very significant indeed. For example, one major oil company has reported that the overall cost of corrosion in that company was equivalent to 6.5% of the net asset value, estimated to be more than £200million over 3 years[8], and similar estimates have been reported by other organisations[9,10].

The magnitude of these costs is entirely consistent with the estimates given as early as 1971 in the Hoar Report[11] on corrosion costs. The problem with that and similar studies was that although global corrosion costs could be estimated it was difficult to reduce them because they proved complex to itemise, isolate and control. Developments in computer power and availability mean that the information now can be obtained and costs identified and tracked. Attention is being focused afresh, therefore, with ‘Cost of Corrosion’ initiatives in the UK[12], USA[13], and elsewhere.

There is now a strong trend towards using a combination of more modern instrumentation for corrosion surveillance purposes, which employ more precise incremental measurements. Data evaluation and correlation with process parameters are undertaken in real time in order to obtain a continuous prediction of equipment condition. Whilst these systems do not guarantee plant health, they can provide a reliable indication of service environments that are harmful to the plant, enabling operators to take timely action and to reduce both the duration and the degree of corrosion attack. Some examples are provided in the following section to illustrate the capability of this technology to assist operators to avoid corrosion damage.

2.1 Acid Condensation Corrosion

The graph below, (Figure 1), shows data obtained on a large power boiler which was being fired on Orimulsion fuel. The boiler was fitted with a wet scrubber flue gas desulphurisation (FGD) system to remove SO_2 and the exhaust gas was reheated to prevent condensation. Nevertheless, substantial corrosion damage was taking place in the flue gas outlet duct downstream of the scrubber, costing a great deal of money for repairs, lining, and general maintenance.

A programme of on-line monitoring was initiated to establish when corrosion was taking place and under what conditions the flue gas could become condensing.

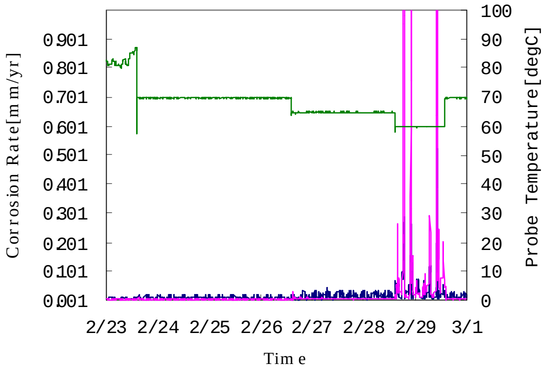

Figure 1 – Dewpoint condensation behaviour in a power plant flue duct

It can be observed from the graph that as the probe metal temperature (upper trace) was lowered, acid dewpoint condensation corrosion took place at temperatures below approximately 65ºC. As soon as this condition was established, very high rates of corrosion would occur on the flue duct walls. A short programme of field trials established that conditions that could support continuous condensation could be established under certain firing conditions of the reheater furnace, especially if moisture removal by the mist eliminators on the outlet from the FGD system was less than optimal.

The field trials were extended to enable the corrosion surveillance instrumentation to remain in service in the plant. The benefits of the project are illustrated in the graphs show below (Figure 2) which present the reduction in reheat cost and the resultant savings during the ensuing twelve month period.

1997

Reheat flux

1998

Savings

(x 1000 Yen/month)

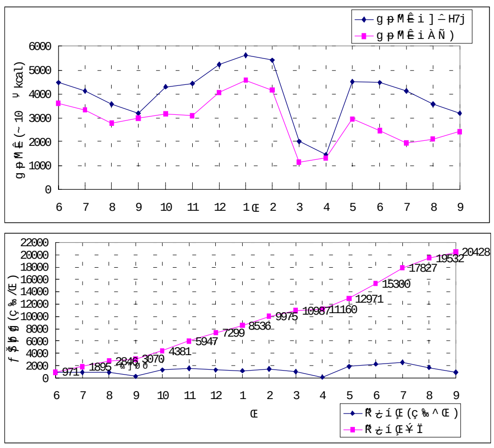

Figure 2 – Savings achieved by management of the power plant dewpoint corrosion problem

The upper graph shows the reduction in heat flux (equivalent to the reduction in fuel) required from the reheater in order to dry the flue gas and maintain it in a non-condensing condition in 1997(upper line) and 1998 (lower line). The lower graph shows the associated monthly (lower line) and cumulative (upper trend) savings. Note, these figures do not include provision for reduced maintenance activities or minimised plant downtime, both of which previously had contributed significantly to the overall cost of the power plant corrosion condition.

2.2 Process Corrosion Surveillance

A second example is taken from work on the ammonia absorption train on a large coke oven plant. This installation had been susceptible to significant and unpredictable variations in corrosion rates during normal operation, such that there was considerable uncertainty how long the plant could remain in service before it required refurbishment activities. It was also recognised that variations in the corrosion condition might be related to poor process chemistry in the absorption unit, which had implications on the efficiency of ammonia removal, but in the absence of on-line corrosion data it was not possible to gain control of this long-standing problem.

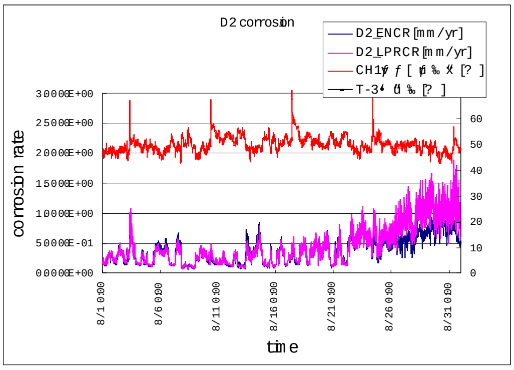

Figure 3 – Corrosion behaviour in a coal plant ammonia absorber system

The data shown in Figure 3 illustrate corrosion behaviour on the plant during a one-month period. Several points are evident from the trends shown on the graph. First, the upper temperature trace exhibited regular weekly excursions, which coincided with a process circuit purging cycle. Second, on some occasions, increased corrosion rates were linked to this excursion, but on other occasions the corrosion rate (lower curves) did not increase unduly with temperature. This meant that temperature excursions themselves did not necessarily cause increased corrosion attack, though the times that they took place could be related to increased corrosion rate. However, the most striking thing about the graph is that at the start of the period, the corrosion rate was reasonably low, but towards the end of the month the rate increased progressively without abatement. In point of fact it reached a maximum of 6 to 7 times the background corrosion rate. This was equivalent to a six to sevenfold reduction in the service life of the plant during periods when control was lost on corrosivity of the process environment.

It was evident that in such circumstances that there was no real control of the corrosion condition of the plant. Inspection activities when the plant came off line amount to nothing more than accounting for how much damage had been sustained during the preceding period of operation. This is not helpful in deciding what might be the background cause of attack.

After a short period of operation with the benefit of the on-line corrosion information it was possible to relate periods when control of the corrosion environment was lost to particular circumstances on the plant. This particular example was traced to a dysfunctional pH sensor that had developed an impervious crystalline coating, which prevented it giving an accurate reading. Further work revealed that excursions in corrosion rate were linked to the molar ratio of two components of the process liquor (see Figure 4).

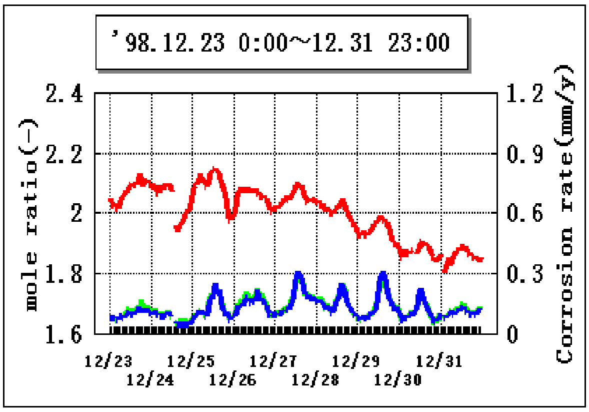

Figure 4 – variations in corrosion process liquor molar ratio (upper trace) rate and corresponding transients in corrosion behaviour (lower curves – near-coincident light blue & dark blue traces).

However, these results were useful to the plant not only because they clarified the cause of corrosion behaviour, but also because variations in the molar ratio also controlled the efficiency of the ammonia absorption process. The data therefore facilitated optimisation of the process operation to minimise corrosion damage while maximising process (ammonia absorption) efficiency, thereby increasing the productivity of the plant while minimising maintenance and eliminating unscheduled outages.

2.3 High Temperature Corrosion Surveillance

In another development, on-line electrochemical sensors are being used to monitor changes in the corrosivity of flue gases adjacent to furnace water walls in pulverised coal power generation plants and directly fired process heaters. The progressive introduction of ever-more stringent regulations to reduce NO_x emissions has resulted in an increase in the risk of water wall tube wastage in large power boilers, refinery process heaters and municipal waste incinerators. The leading combustion modelling company, Reaction Engineering International, Inc., has combined state-of-the-art computational fluid dynamics (CFD) techniques with in-situ sidewall sensors, such that the risk of waterwall degradation due to impingement by fuel-rich combustion gases can be predicted and then verified in real time while the plant is in service.

Data shown in Figure 5 illustrate the degree of sensitivity of the high temperature electrochemical sensors used in the system. Even the slightest change in furnace stoichiometry is reflected immediately by what is, in effect, an electrochemical corrosion sensor. However, the objective in this case is not to measure the rate of attack (which of course can still be done if desired). The new objective is to identify the risk of attack in real time and before any significant damage has been sustained, thereby reducing both the duration and cumulative extent of degradation sustained by the waterwall tubes, while maximising the efficiency of NO_x reduction at lowest cost.

(Provided that the wall tubes are not damaged, staged combustion is a considerably less expensive method of NO_x minimisation than are catalytic $DeNO_x$ reduction measures once the NO_x has been generated). This example probably best illustrates the direction of future corrosion sensing technologies – i.e. the objective will be to manage the service environment, rather than as in the past, to obtain a retrospective indication of how much damage has already been sustained by the plant.

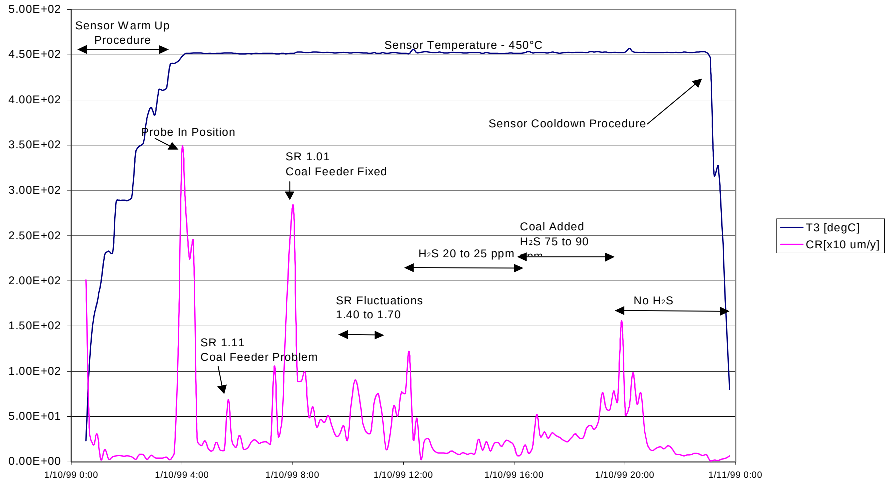

Figure 5 – Electrochemical response at the water wall of a coal-fired furnace environment

3. 'Condition' Monitoring

Condition monitoring is a catchall term for a collection of plant health techniques, especially machinery based monitoring. Developing originally from vibration-based protection systems, the majority of condition monitoring equipment was used on relatively large machinery in plants, such as large motors, fans, pumps, gearboxes and turbines which caused major disruption to plant availability and production if they required unexpected maintenance[1,2].

It was recognised that the onset of vibration signified that a machine was developing a fault that eventually would require attention. This information signified that a change in the 'health' of the equipment had taken place. Importantly, the 'health' information was available long before vibration became so excessive that it would cause the machine to be tripped. This type of fault did not always represent the problems with the rotor dynamics of the system, however, but did represent performance-based problems. Equipment health monitoring systems used the same type of sensors and electronics as protection systems but allowed the condition of equipment to be predicted. The lead-time so obtained could enable significant savings to be made[2].

Remote systems were launched initially by the users of large machinery on offshore platforms. The offshore industry in Norway pioneered most of the remote monitoring of large turbines and compressors[3] where savings in maintenance costs of over 30% were reported, with savings in fuel costs of about 2-3%.

The above techniques led to more comprehensive approaches in maintenance practices. Predictive condition monitoring emerged, as a major maintenance technique[4,5] creating large reduction in maintenance costs as shown in Figure 6.

The histogram shows that although an approximate one-third reduction in operating and maintenance (O&M) costs was achieved by moving from a ‘corrective’ – more realistically termed a ‘breakdown’ or ‘fix as fail’ – repair strategy, to a ‘preventive’ regime, this yielded only approximately half of the maximum cost savings. Although more difficult to introduce than the simple scheduling of traditional maintenance activities required for preventive action, the EPRI research showed that the introduction of ‘predictive’ maintenance strategies could yield a further one-third reduction in O&M costs.

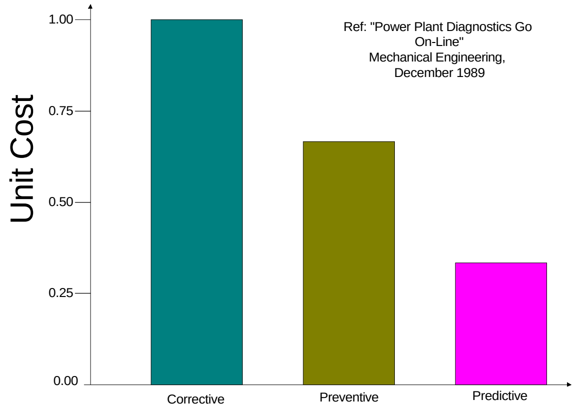

Figure 6 – Relative cost of maintenance approaches

More recently, condition monitoring developments have been introduced in the nuclear industry[6], where it was reported that their application yielded an overall ~40% reduction in O&M costs, compared to conventional plant maintenance approaches.

Only comparatively recently was it realised that on-line corrosion monitoring is the equivalent plant health appraisal technology for pipelines and vessels. It is for this reason, then, that the traditional machinery monitoring (Performance and Vibration Based Systems) and corrosion monitoring are the primary building blocks that enable the introduction of a comprehensive plant-wide condition management strategy.

4. Criticality Appraisal and Risk Based Inspection

Modern instrumentation systems have the capability to provide comprehensive surveillance throughout a process plant, this could be expensive to undertake, and thus a means by which surveillance can be targeted for maximum benefit is required.

In an existing plant, targeting may be achieved because installation of the surveillance package is prompted as a response to manifested damage. This response effectively is the plant surveillance equivalent of a ‘fix-as-fail’ maintenance response. In a more managed environment criticality appraisal methodology for risk-based mechanical integrity or risk-based inspection can be harnessed to ensure that surveillance instrumentation is installed on the most critical and cost-beneficial sections of the plant[14, 15].

The risk-based methodology, such as is illustrated in Figure 7, can ensure that inspection resources are deployed optimally for each plant component and that the degree of inspection undertaken is proportional to the combined engineering and operational risk on each section of the plant. When applied in conjunction with modern surveillance instrumentation the effectiveness of the approach is magnified. The systems provide continual verification that calculated risk is consistent with that actually experienced when the plant is in service. Excursions away from the expected norm are annunciated immediately to operations and engineering personnel, enabling prompt and effective remedial action to be formulated and implemented.

The plant inspection function frequently is confused with the monitoring activity. For example, a section of plant that previously was found to sustain damage subsequently is reported to have been put on a 'monitoring' programme. In fact what will happen is that it will be inspected more frequently than otherwise might have been the case, but this activity is still relatively infrequent – even on a plant item that has caused severe disruption it is rare for the item to be accessible for inspection more frequently than at six-monthly intervals. Such a programme provides no control of the problem whatsoever.

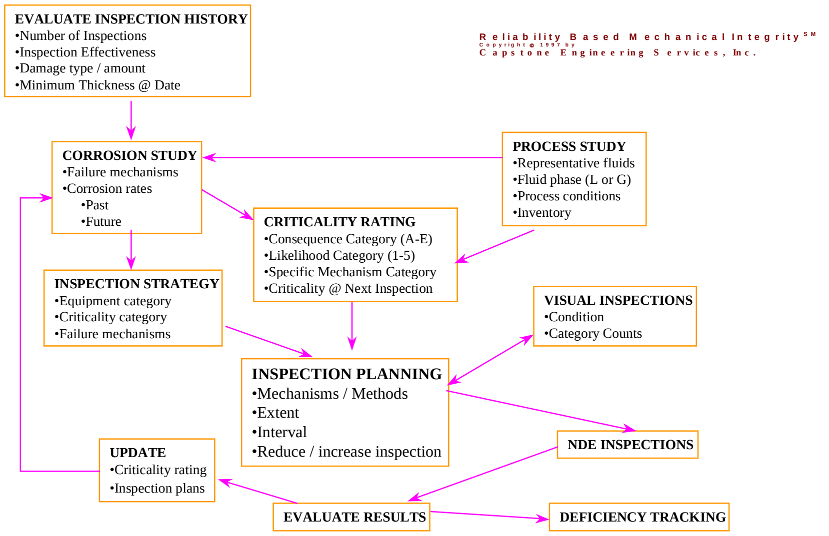

Figure 7 – Flow-chart illustrating the Risk-Based Mechanical Integrity methodology

Inspection is necessary, important, but time-consuming and expensive. What inspection brings is accountability; the inspector verifies the actual condition of equipment in terms of cumulative damage ***after*** a period of service. This normally requires the plant to be off line in order to allow access for the inspector. The purpose of surveillance is to provide a means of obtaining an automated, near real-time indication of plant condition at minimal incremental cost and without interfering with plant operation or production. On the basis of data obtained from monitoring, a prediction of plant condition can be made which subsequently can be confirmed by inspection at infrequent intervals. Inspection cannot replace on-line monitoring, any more than 'monitoring' can (or should) replace 'inspection'. The purpose of each activity is distinctly separate even though they are complementary when monitoring and inspection are applied in tandem. Furthermore, neither activity is so effective when used without the other.

5. Integrated Systems

The foregoing sections have dealt with issues relating directly to plant health appraisal, and have presented a few examples of recent installations. On the one hand, these examples were aimed directly at minimising real corrosion problems, but they were also conducted to develop the concept of advanced health assessment and condition management techniques for large static plant components. This approach is starting to be employed in conjunction with SAP-type enterprise resource planning systems, which originally were intended to optimise financial resources relating to the overall management of a business. To date these systems have largely ignored process design and equipment health considerations, which demand input of specialist knowledge outside the normal realm of cost accounting. Developments in condition management should be considered in the wider context of manufacturing and production information systems and of process optimisation[16,17].

5.1 Modelling

Process modelling was developed as a means of optimising the production capacity of process plants. If undertaken continuously in response to variations in product demand, process modelling can provide the means to compare the efficiency of the production mix with the theoretical optimal that the plant is capable of producing. The difference between theoretical and actual efficiency provides plant operators with an indication of the potential for improvement in the yield of the plant.

In a parallel development, mechanical engineering models can be developed which allow actual plant degradation and maintenance experience to be compared with a theoretical model of expected failure. The comparison provides benchmarks against which to gauge relative improvement in maintenance efficiency.

5.2 Process Optimisation

At first sight it may be imagined that process integration is not connected to condition management or inspection, and this has been the case in the past. However, there is every incentive for complete integration of all these production-related technologies.

Process integration was developed initially as a means of optimising the design of chemical and petrochemical process plants. Process optimisation is still only a pre-construction or pre-production exercise. This is surprising because many process plants are designed for batch manufacture of a range of products, each of which will require continuously changing optimisation parameters. Process optimisation and re-optimisation 'on the fly' can enable companies to meet variations in market demand and maximise production efficiency and overall profitability.

When embodied in a modern integrated plant environment, of the type portrayed in Figure 8 (below), dynamic plant health assessment, process modelling and process integration provide the means to augment plant reliability, availability and safety with maximum capacity and flexibility.

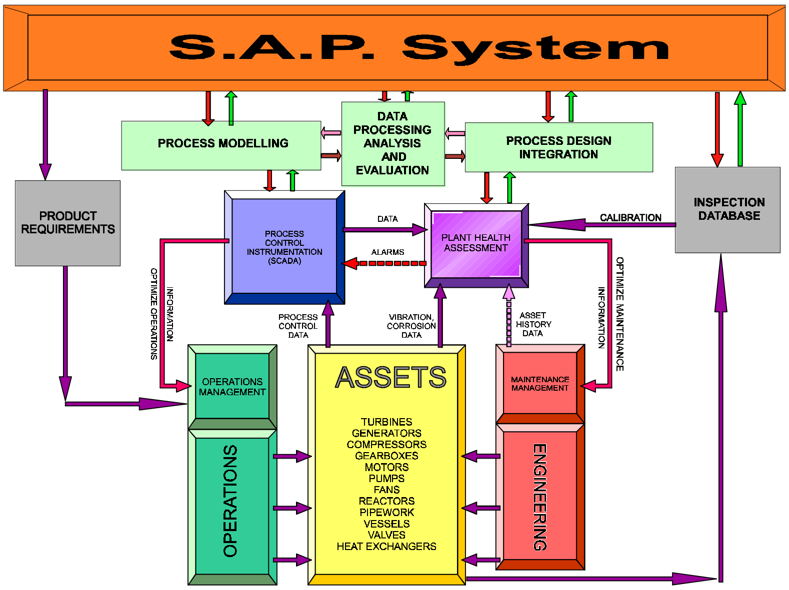

Figure 8 – Plant health module within the business management model

6. Discussion - Plant Condition Management

In plant health terms, monitoring and measurement both cost money and are only half way stage on the way to the real objective, which is the avoidance of cost and plant damage. Condition management makes proper use of both activities but exploits information derived from them to generate money for the plant operator. Good plant condition management therefore should be the objective of materials and machine health specialists.

The change has further implications: in the past, corrosion and condition monitoring were considered to be service activities, providing only a ***reactive*** strategy. Condition ***management*** embodies a ***pro-active*** stance on plant health. This fundamental understanding should not go unrecognised by the materials and condition monitoring specialists. Condition management is a huge opportunity for technical specialists to provide the best possible service to clients, whether internal or external. The same specialists also will be able to derive the maximum direct benefit from their expertise.

Conventional alloy selection, coating specification and failure investigation skills will always be required, as will inspection services to confirm the condition of the plant. However, the phenomenon labelled corrosion should no longer be regarded as a necessary evil as it is only a problem when out of control. The electrochemical behaviour characterising corrosion is also the means by which on-line plant health management can be achieved.

Performance evaluation is also important initially in determining that a plant meets its guarantee points and, subsequently, to ensure it continues to be operated at or near its design operating condition. Maintenance practices are being combined ever more closely with operational practices to ensure that plants have the highest reliability with maximum efficiency. When a new plant is built, its cost amounts to only about 7-10% of the life cycle cost. Maintenance costs represent approximately 15-20% overall. However, operating costs, which in the case of a power plant for example, consist essentially of energy costs, make up the remainder, and amount to between 70-80 % of the life cycle costs of the facility. This brings performance monitoring to the forefront as an essential tool in any type of plant condition monitoring system. Operating a plant as close as possible to its design conditions will guarantee that its operating costs will be reduced. As an illustration of the opportunity cost this represents, large fossil power plants currently being commissioned range from 600 MW - 2800 MW. The fuel costs for these plants will amount to between US $72 million and US $168 million per annum. Therefore, savings of 1% - 3% of these costs can amount to an overall cost reduction of upward of US $1 million per annum(18,19).

A change in approach is clearly necessary in order that the full benefit of integrated plant condition management and control can be recognised and exploited. Improved control and enhanced performance monitoring will enable shut down intervals to be extended without increasing the risk of premature or unexpected failure. In turn, this will increase the confidence of operations, inspection and management personnel in the effectiveness of unified plant administration.

7. Conclusions

The improved speed and capacity of computerised information systems mean that techniques, that were developed for plant condition monitoring, corrosion monitoring, inspection, optimisation and modelling, now can be integrated to provide cost-effective real time plant health management.

The development route can be designed such that real corrosion problems, and machinery performance problems are addressed in the process, thereby providing an immediate pay-back on investment while training plant personnel in modern techniques of pro-active corrosion control.

There will continue to be a requirement for conventional materials selection, inspection and maintenance activities. However, the benefits of the new approach are that it enables process plant operation to be safer, more flexible, more reliable and more profitable than was possible in the past.

Although some additional investment may be necessary, in many cases only a redistribution of existing budget is required, and take-up of the modern strategy is inhibited to a greater degree only by a requirement to develop suitable applications expertise.

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