COMPUTERISED CORROSION MONITORING STEPS TOWARDS PREVENTING UNEXPECTED CORROSION FAILURES.

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Traditionally the consequences of corrosion on process plants have been assessed on the basis of cost. However, major failures occurring as a result of corrosion can also have a considerable hazard potential. In the past, corrosion has been monitored manually. Recently, improved corrosion monitoring techniques using available computer and automation hardware have improved our ability to detect unexpected corrosion. The use of these techniques provide continuous monitoring of corrosion which can alert operators/engineers immediately of a corrosion incident permitting control of the incident before a major failure occurs.

INTRODUCTION

Corrosion has long been recognised as a serious reliability and maintenance problem on process plants and refineries. Traditionally the consequences of such corrosion have been assessed on the basis of cost. Extensive maintenance effort and unplanned shut downs caused by corrosion cost the petro-chemical industry millions of pounds annually. However, equipment failures on process plants occurring as a result of corrosion can also have a major hazard potential. Explosion, serious fires and toxic leakage can all be precipitated from relatively minor equipment failures caused by corrosion.

Until recently corrosion has been monitored on-line with corrosion probes which are manually read. Other corrosion indicating data e.g. process stream analyses are correlated manually to assess the corrosion potential of a process system. While these methods can provide a reasonable evaluation of long-term corrosion, the low frequency of data collection and the time involved in data processing precludes reliable and timely control of short term corrosion incidents.

At refineries, this problem is becoming more severe as increasingly corrosive and varied feed stocks are now being fractionated. These existing corrosion monitoring techniques can therefore no longer provide satisfactory assurance against the risk of equipment failures caused by corrosion. There is also an increasing awareness of the need for both safety and reliability in plant operation.

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With the aid of computers, on-line corrosion monitoring is being developed by Esso using three interrelated approaches: directly measuring the corrosivity of a process with corrosion probes or other corrosivity monitors; indirectly assessing the corrosivity of the process by evaluating selected process data; and directly measuring and statistically evaluating corrosion as metal loss of the process equipment using both on-line and turnaround NDE techniques.

THE CONSEQUENCES OF CORROSION

The effects of corrosion in process plant, in particular the cost, have been widely and variously described in the literature. At Esso the cost of corrosion has been evaluated not only in terms of cost but also plant reliability. As a cost consequence, the annual maintenance budget for Esso's European refineries exceeds 30M$. Of this figure approximately 25% can be attributed to corrosion. In terms of reliability, a recent study of the reliability of catalytic reforming units showed that 18% of unplanned unit shutdowns were caused by corrosion. A further 14% were also indirectly affected by corrosion.

Normally the physical consequence of corrosion is a small leak in process equipment or piping. The effects are localised and relatively easily controlled. The risks associated with such leakages are low particularly as modern refineries are operated with few, if any, persons on site most of the time.

The potential does exist however for corrosion to cause equipment failures of much greater consequence. Refineries process fluids that can be at high temperature and at high pressure, the process streams often contain highly flammable liquids or gases, and they can contain constituents that are highly corrosive or toxic (hydrogen sulphide for example is present in many process areas of a refinery). Therefore there is always the risk that a major hazard will develop from corrosion damage. The following examples illustrate the damage that can occur.

In 1969 a large and intense fire with several explosions occurred at a catalytic reforming unit at Esso's Fawley refinery. The fire started when the inlet header piping of an air fan cooler corroded through. The air fan was used to cool the effluent circuit of the hydrofiner unit which sweetens the feed to the reformer. The principal corrodent was hydrochloric acid which formed in the hydrofiner reactor by conversion of organic chlorides in the feed. The organic chlorides entered the unit when the normal naphtha feedstock was supplemented with by-product streams from another unit.

Another major fire which occurred at an Exxon refinery in the United States centred on the fluid catalytic cracking light ends unit. Acid condensate corrosion occurred in a process piping 'dead leg'. The stagnation of the process fluid within the dead leg allowed temperatures to fall locally below the acid dew point. Acid condensed and severe corrosion occurred. Leaking naphtha ignited and a significant part of the unit was destroyed.

Sometimes corrosion can cause hazards which are not always obvious. When steel corrodes in an aqueous acidic environment, atomic hydrogen is generated at the metal surface. Most of the hydrogen atoms couple to form molecules and are carried away. The remaining hydrogen atoms can be absorbed into and permeate through the metal. The conversion to molecular hydrogen gas will then occur at discontinuities in the metal or at the outside metal surface. In one example the hydrogen diffusing out of a vessel surface was trapped beneath a nozzle reinforcing pad. The pressure of hydrogen under the pad rose to higher than the internal pressure of the process vessel. During subsequent downtime maintenance a bleed hole was drilled through the reinforcing pad. The hydrogen in the void was ignited by the drill tip and an explosion occurred.

Not only process but also utilities equipment is susceptible to corrosion. High pressure steam is generated on refineries in large quantities. At Esso's refinery in Rotterdam in 1982 severe internal corrosion of the main steam boiler occurred which, coupled with fatigue induced by the vibration of the boiler tubes resulted in simultaneous multiple tube failure and explosive damage to the boiler.

There is a current worldwide concern about boiler feed water de-aerators. Three catastrophic failures of these very large storage vessels have occurred in the last two years. A corrosion-fatigue type mechanism has been proposed for the failures. Improvements in water quality and corrosion control are being developed to prevent recurrences.

While major hazardous failures of this type caused by corrosion are rare events, the severity of the incidents provides added incentive for improved corrosion monitoring and hence control.

MANUAL CORROSION MONITORING TECHNIQUES ARE NOT ALWAYS EFFECTIVE

Esso's Refineries have actively monitored corrosion in process units for many years. A variety of both on-line and down time techniques have been used. On-line monitoring has been performed using corrosion coupons, corrosion probes and non-destructive techniques for measuring metal thickness and thereby metal loss by corrosion.

Pre-measured and weighed corrosion coupons are inserted into a process stream on racks. After a period of service (say six months) the coupons are removed, reweighed and measured and the corrosion rate calculated.

Two types of corrosion probe have been commonly used in refineries: electrical resistance probes and linear polarisation probes. With the electrical resistance probe, the progressive loss of material from a wire loop (or tubular) element inserted into the process stream is measured as an increasing electric resistance. Repeated measurements at intervals provides corrosion rate data. By using an element of similar material to the process equipment an assessment of the corrosivity of the process fluid with respect to the equipment material can be made. Electrical resistance probes can be used in both aqueous and non-aqueous, liquid or gaseous process streams. With the linear polarisation probe the potential required to polarise the probe element in the particular corrosive environment is measured. In this way, the corrosion rate is measured directly and instantaneously. Linear polarisation probes only function however in ionised aqueous environments. Although aqueous fluids are frequently the primary corrodents in refineries, process streams usually contain a mixture of hydrocarbon and water. The use of linear polarisation probes is limited by this factor.

Provided the corrosion probes are located such that the most aggressive components of a particular process stream are being monitored, an assessment of the corrosivity of a process throughout a complete section of the process unit can be made. The metal loss from the process equipment can however only be inferred as the corrosion rates of the probe elements themselves are measured not the equipment or piping. Direct metal loss measurements are required to support the corrosivity indications provided by the probes. To support the corrosion probe measurement, on-stream process fluid sampling is also used to assess the corrosivity of the process environment. Analyses of crudes and products bought in for processing by refineries are analysed for reactive sulphur compounds, organic acids, salt content and nitrogen content. These will indicate the potential for corrosion in various units used in processing crudes through the refinery. In lower temperature processes, aqueous corrodents are the primary cause of corrosion. Analyses of water samples for pH, hydrogen sulphide, ammonia, chlorides and other contaminants are major contributors to corrosion monitoring by corrosivity assessment.

Ultrasonics and radiography are employed to measure the wall thickness of process equipment and piping on-stream. While providing a reasonably accurate measure of wall thickness both techniques are limited. Corrosion in process equipment is frequently very localised. 100% examination of a process unit by radiography or ultrasonics is impossible. Selected sample examination requires experience, good judgement and some good fortune to assess where the most corrosion is likely to occur. Also, to make the measurements, insulation must be frequently removed and access to the areas selected for measurement is often difficult. Scaffolding might be required for example. Process temperatures can also limit the use of these techniques from the standpoint of the capability of the inspection equipment. Vibration and the process fluid itself affect the accuracy and definition of both methods, particularly radiography. Personal safety considerations further restrict the use of on-line inspection.

The principal limitation of all the above techniques is the frequency of measurement. All the methods are labour intensive and time consuming both in obtaining the data and then later evaluating them. Measurement frequency is typically once per week for corrosion probe measurement and sample analysis and once per month at best for NDE wall thickness measurement. If severe corrosive conditions are expected in specific areas the measurement frequency can be increased but, in general, a higher frequency of measurement is impractical.

In some units the rate of corrosion is sufficiently low and constant that low frequency measurement is adequate. However, corrosion can be extremely rapid in some process units, particularly where inhibitors are used to provide corrosion protection for materials with low corrosion resistance. A break down of inhibitor facilities in, for example a naphtha desulphurisation unit can result in leakage through the process equipment in days rather than weeks. Most refineries were designed to process specific types of crude from both processing and corrosion standpoints. In recent years refineries have resorted to spot purchase of crudes and crude slates are frequently changing. In a large refinery a tanker load of crude is processed in two to three days. The potential for corrosion of different crudes can vary considerably. It is apparent therefore that a system of corrosion monitoring based on weekly measurements is no longer sufficient to provide adequate assurance against unexpected corrosion occurring. To overcome the manpower problems involved in increasing the monitoring frequency, automation/computerisation had to be considered.

AUTOMATION/COMPUTERISATION OF CORROSION MONITORING

Since 1980 Esso have undertaken a programme to up-grade the methods of corrosion monitoring and control on its European refineries. The intent of the programme is to improve standards of both safety and reliability by minimising the number of plant leakages, failures and shutdowns caused by corrosion. The cost and effort of such programmes is considerable and therefore their implementation has been progressed in several distinct stages. (Figure 1)

The first (Documentation) stage at each refinery involved surveying every process unit to assess the potential for corrosion and corrosion problems. The requirements for corrosion monitoring were then developed based on this assessment. These requirements included: the number, locations and types of corrosion probes; stream analyses, pH analyses and their frequency; non-destructive testing plans for both on-stream and down time metal thickness measurements. The refineries each produced a refinery-specific document containing all the above considerations and detailed monitoring requirements which is known as the Corrosion Control Programme.

At the second (Implementation) stage, the requirements of the Corrosion Control Programme were implemented. Corrosion probes were added or relocated as required. Stream sampling procedures were instigated. On-stream NDT programmes were initiated and down-time NDT plans modified to comply with the Corrosion Control Programmes. All of Esso's European refineries have completed both the Documentation and Implementation stages of their improved corrosion monitoring programme. While at this point the standards of corrosion monitoring can be considered high, the systems used are all manually based and are subject to the limitations described previously. For greater assurance of preventing corrosion related failures and hence of safety and reliability, automation of corrosion monitoring and computer assistance is necessary.

The third (Computerisation) stage of the corrosion monitoring programme is now complete at three of Esso's European refineries and is underway at most of the remainder. Two aspects of computerisation have been examined: data acquisition and data management. (Figure 2) Both aspects can be applied to the three interrelated approaches being followed to monitor corrosion: direct measurement of process stream corrosivity by corrosion probe or similar device; indirect assessment of process stream corrosivity by evaluation of selected process data; and direct measurement of metal loss by corrosion using NDE techniques. This move to computerisation has coincided with major improvements in the overall computerisation of refineries. This was helped significantly in the development of the corrosion monitoring programmes.

Corrosion probes (electrical resistance type) are the primary tool for on-line corrosion measurement in the refineries. Between 20 and 100 have been installed at each refinery, depending on its size and its process unit complexity and types. To automate the acquisition of data from the probes, they are hard-wired via multiplexors to a computer. The multiplexors (linked to up to 15 probes) read each of their probes sequentially and repeatedly and feed the data to the computer. The corrosion probe multiplexor was originally developed for Exxon (Esso) in the United States in 1976. Probe reading frequency is typically once every 30 minutes. Check and reference readings are taken at the same time to monitor the probe integrity and performance. Each reading of the probe, which is a measure of the metal remaining on the element of the probe, must be compared with previous readings to obtain a corrosion rate measurement. The half hourly frequency is such that almost continuous corrosion rate data is obtained in this way. It should be emphasised that the measured corrosion rate is that of the probe element and not necessarily that of the process equipment in which the probe is installed. The probe reading is therefore a 'corrosivity indicator' which tells the operator that process conditions have changed which have changed the corrosive potential in the unit. The corrosion monitoring computer manages this data to provide daily reports to the refinery corrosion engineer and the operators. In some units in which corrosion can proceed very rapidly and may be controlled by inhibitor injection, probe data showing higher than expected corrosion rates can be alarm linked to the operations control in a similar manner to process data.

Further management of probe data is either by the corrosion monitoring computer or by the refinery's general purpose computer. Typically the daily corrosion rate is used as the base data form. This simplifies comparison with long term process data which is also managed in this form.

In some refineries automatic pH meters will also be linked to the corrosion computer. pH measurements of entrained aqueous components of process streams are an essential part of corrosion monitoring. In many refinery processes the hydrocarbons are essentially non-corrosive and the primary corrodents exist in the aqueous components.

Stream analyses are also an important contribution to corrosion monitoring but unfortunately cannot be reliably automated. However, refinery support laboratories normally have computer contact with the refinery computers The analytical data can be manually entered into the computer for processing and comparison/support with corrosion indicating data.

In some process streams corrosion probes are ineffective for corrosion monitoring or maybe beyond their design limits (high pressure and/or temperature). In these cases an assessment of the process data together with stream analyses can provide the best method of monitoring corrosivity changes. Process data can also provide support for corrosion probe data. From the overall mass of process temperature, pressure and flow rate data available (typically collected at a six minute frequency), some can be selected by the refinery corrosion engineer to be the best indicators of corrosion problems in a process unit. For example, equipment is often maintained above the dew point of the process stream to prevent corrosion by acidic condensate. In this instance temperature data can provide a good indicator of the risk of corrosion occurring. A corrosion probe located in a water collection point downstream can then be used to indicate the likely corrosivity of the condensate when it occurs. Together they form an effective means of monitoring corrosion.

It is important that process data is understood and monitored by the corrosion engineer. Variations in process conditions within a given operating envelope are not a concern to the refinery operators, however these same variations can significantly alter the corrosivity of a process stream. The operating envelope acceptable to the corrosion engineer may be markedly different to that which is acceptable to the operator.

Corrosion probe data, analyses, and process data are only corrosivity indicators, none give an actual measurement of corrosion. Ultrasonic and radiographic non-destructive examination must be used to measure metal loss from piping and equipment. This is primarily an activity for turnaround down-times because insulation removal and scaffolding is often required. However a significant amount of these types of inspection are undertaken on-stream to supplement corrosion data.

Metal loss measurements have to be made on a small sample basis. To date there are no means for assessing the localised metal losses in either a complete piece of equipment or section of piping. By concentrating the sample measurements in areas or sections in which corrosion is normally expected, it is believed that reasonable assessment of the corrosion occurring can be made. The sampling technique however generates a vast quantity of data. Each item of equipment or each section of piping may contain up to 50 measurement points. Items of equipment and sections of piping will number thousands. Computerising this data is essential for their reliable interpretation and use.

Storage and management of the data by computer is straightforward and a variety of reporting functions can be employed. Long and short term corrosion rates and remaining life predictions are the two most common. In addition the computer can programme inspection schedules, based on both inspection results and also on governmental requirements; problems associated with inspection, for example scaffolding needs; and maintenance requirements.

At present the inspection data is manually entered into the computer. However portable data terminals combined with ultrasonic thickness meters are now available which eliminates the pen and notebook reporting from the field inspectors. Bar strip identification of measurement points further simplifies the transfer of data into the computer.

WHAT IS GAINED BY COMPUTERISING?

From safety and reliability standpoints the computerising package produces gain by: improving response to corrosion incidents; improving the prediction of corrosion; and improving control of corrosion. Additionally, manpower is used more effectively with a much improved level of corrosion monitoring.

The high frequency acquisition of both corrosion probe and process data significantly improves monitoring response. Anticipation of failures is more assured as all process changes and feed changes can be followed. A two to three day crude slate run, for example, will not be 'missed' by the corrosion probes as was possible when the probes were read manually once or twice a week. The essentially continuous monitoring achieved can alert process engineers and operators to unexpected corrosion incidents in sufficient time to enable corrective or controlling actions to be taken. The aim is to prevent any shutdown caused by corrosion, but a system can be particularly justified if a major failure can be avoided.

The continuity and extent of data collated by computerising will also improve our ability to prevent corrosion in refinery units. Frequently the analysis of corrosion failures has floundered through lack of data. However the extent of information now available will improve these analyses and hence our understanding of corrosion in the refineries. This may then lead to improving our ability to control corrosion by process means.

FUTURE POSSIBILITIES

Ultimately, process/corrosion algorithms for particular process can be developed. These will enable computerised control of the process corrosivity by closed loop control of the process variables affecting corrosion and other corrosion control techniques such as inhibitor injection. At this point, computerised monitoring can become computerised control of corrosion.

E8/RWG/CAM

FIGURE I

DEVELOPMENT STAGES OF A COMPUTERISED CORROSION MONITORING PROGRAMME

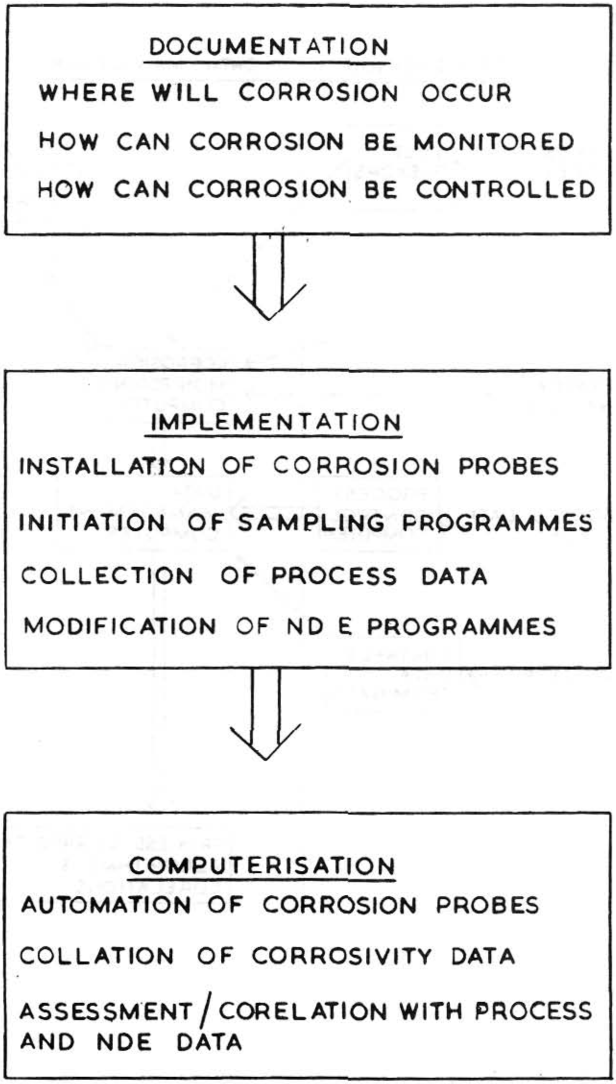

FIGURE 2

COMPUTERISATION OF CORROSION MONITORING

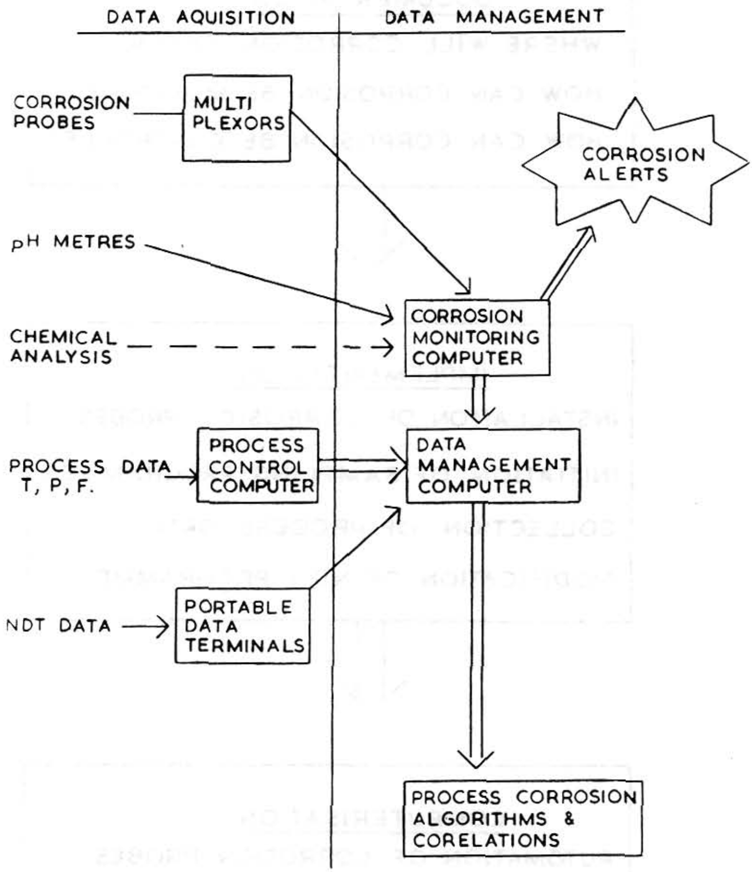

FIGURE 3

BENEFITS OF COMPUTERISED CORROSION MONITORING