MICROBIAL CORROSION IN OIL INDUSTRY: A PRELIMINARY SURVEY OF THE PROBLEM

BY:
NOEGROHO HADI HS.

In 1977 Warren Spring Laboratory was authorised by the Engineering Materials Requirements Board of the Department of Industry to carry out a limited survey on the extent and magnitude of microbial corrosion in British Industry. The need for the survey arose because, despite all the microbial corrosion work which has been carried out in the past and the protection techniques which have been developed, microbial corrosion incidents continue to occur, often causing considerable financial loss to industry.

A questionnaire which would enable as much information as possible on microbial corrosion to be obtained from a wide variety of firms and organisations concerned in the manufacture and use of metal equipment. Since microbial corrosion has been most commonly encountered as a problem with buried ferrous metals, considerable work has been done to develop techniques for assessing soil aggressiveness. Several of the survey questions were therefore directed to determine whether the recommended techniques were being applied, how effective these techniques were and of further experimental work was required.

The economics of microbial corrosion protection were another area for which information was sought since the ultimate aim of a soil aggressiveness assessment is to enable the degree of protection given to a buried structure to be directly related to the measured aggressiveness. Thus unnecessary protection would be avoided.

Sources of information

Information was obtained from oil industry, particularly those using equipment in microbially corrosive situation, firms engaged in the manufacture of corrosion protection equipment, corrosion consultants and research and advisory centres. Generally, personal interviews were made but in some cases where there was only a little information this was obtained by telephone.

Additional contacts were obtained after the survey had been publicised in some of the corrosion and corrosion control journals when several firms and research associations volunteered to assist in the survey.

The replies revealed that up to 10 per cent of corrosion enquiries received by consultants and advisory centres had some microbial corrosion involvement but frequently it was difficult to assess the microbial contribution in corrosion incidents.

Recognition

Microbial corrosion is only one of many types of corrosion and generally it is only specialists who can readily recognize it. Furthermore the recognition that microbial corrosion is the primary cause of a corrosion failure is often difficult, particularly when the failure occurs in the soil, since other corrosion mechanisms are probably operating. Indeed in many instances it may be found that several corrosion mechanisms, including microbial corrosion, have all contributed more or less equally to the overall corrosion. Moreover there is often a considerable time interval between the occurrence of a corrosion failure and its diagnosis and the primary corrosion mechanism may have been masked by secondary reactions. For these reasons it has been difficult in most instances to determine the importance of microbial corrosion in isolation.

Occurrence of microbial corrosion

The gas, oil, water supply and iron and steel industries are a group which have in the past suffered considerable trouble from microbial corrosion and have now learnt the need for good corrosion protection.

Research and development laboratories, with specialist corrosion personnel, have been set up by these industries to study and advise on corrosion problems and the protection of all underground pipelines and submerged metal structures against microbial corrosion is now very good. Some sections of manufacturing industry, particulary chemical and food manufacturing firms have also found that corrosion protection is essential for their manufacturing operations.

They, too, pay due regard to microbial corrosion. Likewise the aircraft industry is very corrosion conscious and having suffered from microbial fuel contamination problems in the past has introduced maintenance procedures which have almost eliminated their microbial corrosion problems.

It is in the engineering, building and construction, shipping and parts of manufacturing industry where there is more cause for concern. A continuing occurrence of microbial corrosion incidents was reported. The majority of these incidents were in what are now recognized as typical microbial corrosion situations and involved underground pipelines, particularly those in clay soils, fuel storage tanks, ships and marine installations and circulating or enclosed oil and water systems. In nearly all cases where microbial corrosion was reported the structures were unprotected or the protection which had been given was unsatisfactory either because of poor application, poor quality or damage caused during installation.

An example of how corrosion protection can be damaged was given by a local authority. They reported a recurrent problem with underground water pipes in aggressive soils on scattered building sites where constant supervision was difficult. Workmen found the unfilled pipe trenches convenient for the disposal of rubble with consequent damage to the protective coating on the pipes.

The situation where controversy existed in wide use but although they are not reported to be subject to microbial corrosion, corrosion speciallists advise caution in their use in areas where there is a clay stratum. However the few tests which have been done on exhumed steel piles have shown that they suffer much less corrosion in aggressive areas than pipelines.

The negligible corrosion was attributed to the fact that piles were forced into undisturbed rock strata where the availability of organic materials and chemical nutrients is very limited. Also impervious strata such as clay remain dry. In these conditions microbial activity would be restricted and it is known that anaerobic microbial activity decreases very rapidly with increasing depth in undisturbed soils.

Since steel piling is cheaper than alternative methods of piling there could be appreciable economic benefits if the safety of using steel piles in clay strata could be assured. Every opportunity should be taken to ecamine redundant steel piles to enable reports to be made on the safety of using steel piles in clay strata. If additional evidence is required then research work on this subject should be considered.

Another possible problem area could be in the use of stainless steel alloys. These are now becoming economically attractive for use as pipework for small bore central heating

Since no corrosion protection should be necessary they are also being considered for use in underground situations. The alloys however owe their corrosion resistance principally to the formation of an oxide film over the surface of the metal.

Under anaerobic conditions this oxide film may be lost and the underlying metal could become susceptible to corrosion by sulphate-reducing bacteria. If corrosion protection is not going to be given, tests should be done to ensure that the particular stainless steel to be used retains its corrosion resistance in microbially aggressive soils.

Microbial species involved in corrosion

Sulphate-reducing bacteria are generally considered to be the most trouble some micro-organisms involved in the corrosion of iron and steel 2.3 and this was borne out by the survey. In almost all cases where the microbial corrosion of metal structures underground or in marine environments was reported the causitive organisms were sulphate-reducing bacteria.

A few incidents were reported in which the *acid-producing* bacteria of the genus *Thiobacillus* were believed to be involved. There have been suggestions that hydrogen-utilizing bacteria other than sulphate-reducing ones might be active in causing corrosion but no reports were received of such organisms being found. A number of bacterial and fungal species can degrade protective coatings and tapes but with the introduction if non-biodegradable materials this no longer appears to be a problem.

Hydrocarbon-oxidising bacteria and fungi were reported to have been the cause of many corrosion problems in the engineering, aircraft and shipping industries. The destruction of corrosion inhibitors is often the primary cause of corrosion but the bacteria can also produce corrosive organic acids and create differential aeration cells. Sulphate-reducing bacteria can also develop as secondary colonising organisms and add to the problems.
Slime-forming and **filamentous** growing organisms were also reported to be troublesome in heat exchangers and water systems.

The filamentous iron-oxidising bacteria, *Sphaerotilus* and *Gallionella species* in particular, cause problems in the water supply industry by forming deposits *of ferric hydroxide,* called tubercles, in water pipes. These not only cause the formation of differential aeration cells but may eventually cause blockage of the pipes. Sulphate-reducing bacteria can then grow in the oxygen-depleted environment created.

Bacteria contribute to corrosion in various ways[3] and they may be classified as aerobic or anaerobic. The subject of this review falls in the latter category; the most widely distributed and economically important micro-organisms associated with this are the sulphate-reducing bacteria, especially *Desulfovibrio desulfuricans,* whose cells are curved rods (vibrios) of variable length (Fig I) which are sometimes spirilloid, occasionally straight.[2,4]

Their typical size is 3–5 um x 0.5 – 1 um. They are motile by means of a single polar flagellum and are strictly anaerobic. They occur commonly in soil or mud and are non-spore-forming. These organisms obtain their energy by dissimilatory reduction of sulphate to sulphide, that is, the sulphate is the terminal electron acceptor in an anaerobic respiratory process which provides energy for the cell.
In an assimilatory process, a source of sulphur, for example, protein, is used by the cell for biosynthesis. It is the dissimilatory process which is reponsible for the large scale production of sulphide.

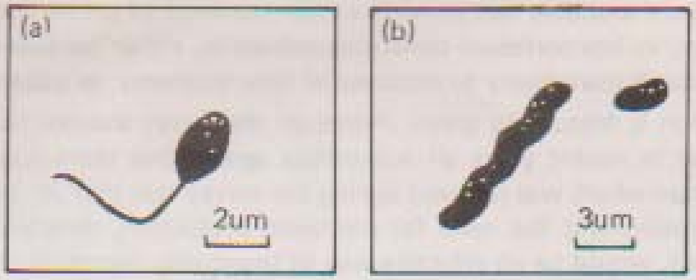

Fig 1 Features of *Desulfovibrio desulfuricans* adapted from electron micrograph pictures,[2] and showing single flagellum (a) and spirallar and swollen forms (b).

Corrosion protection methods

The most commonly used methods for protecting metal structures against corrosion in underground and marine environments are protective coatings and tapes and cathodic protection. When properly applied these methods were reported to provide a very high standard of protection against microbial corrosion.

Corrosion protection is far from being a static field and new materials and techniques are continually being introduced. A new protection technique which has been introduced in recent years is the use of loose polythene sleeving for protecting underground pipelines. This relatively cheap protection method is now gaining wide use. However doubts were expressed in its effectiveness especially against microbial corrosion on account of its susceptibility to damage and consequent permeability to water, bacteria and nutrient salts.

Although surveys both in the UK and the USA have produced very favourable replies there should be continued surveillance on the longterm effectiveness of this particularly cheap type of protection especially in microbially aggressive soils(4). This will enable confidence to be built up of the method continues to perform well.

Biocides are specifically designed to prevent microbial growths in enclosed water systems, in oil emulsions or in oil and fuel systems where water can collect. Water is difficult to exclude because some water from processing will always be present in the fuel tanks. All reports indicated that they are very effective in controlling microbial corrosion, especially when combined with good housekeeping to keep systems free of extraneous organic matter. Problems have arisen with the appearance of resistant microbes and with compatability problems between biocides and fuels but these are being actively investigated.

Economics of corrosion and protection

It was not possible with a limited survey to assess, even approximately, the cost to the country of microbial corrosion. However, the high cost of repairing underground and undersea structures was stressed and costs for replacing gas and water small diameter service mains were given as £20^{-1} and for larger diameter distribution mains as £300–400^{-1}(4).

The actual cost of providing a high degree of protection to underground structures is surprisingly small when quoted as a proportion of the total cost of a structures plus the cost of its burial. The British Gas Corporation (4), for instance, calculated that the cost of the protective coatings and cathodic protection on their high pressure transmission pipelines was only about one per cent of the contract cost of the pipelines

Corrosion awareness

The experience of the corrosion conscious group of industries showed that the corrosion techniques which are available can provide a high standard of protection which is very cost effective. However, in less corrosion conscious industries, either because of lack of appreciation of the problems that are likely to occur or of false economy, or usually both, inadequate corrosion protection is frequently given. Although the survey snowed that corrosion awareness had improved in recent years all authorities agreed that there was much more to be done. One suggestion which was received during the survey was that an easy-to-read booklet on microbial corrosion and the need for corrosion protection, directed towards engineers and others involved, would be an effective way of improving microbial corrosion awareness. A supplementary question on the possible usefulness of such a publication was asked during of survey and there was almost complete agreement that it would be useful.

The effectiveness of corrosion protection, particularly the use of protective coatings, ultimately depends on the skill and care exerciced by workers who carry out the work and deficiencies in this respect were observed, particularly by the building and construction industry. Lack of corrosion awareness is again the major problem. We supported the suggestion that short training courses and films for many workers could lead to an improvement in the standard of corrosion protection given and that the help of the Construction Industries Training Board could be sought on this matter.

Conclusions

It is evident that there are very adequate and cost-effective corrosion protection systems and techniques which can give a high degree of protection to plant and equipment against microbial and most other forms of corrosion. Microbial corrosion problems continue to occur but in nearly all cases these could have been prevented at a fraction of the final cost of the repair bills. Although there are some problem areas where work is being done or requires to be done the major factor responsible for the continuing occurrence of microbial and other corrosion problems is the lack of corrosion awareness in particular sections of industry. It is cleary necessary to improve microbial and general corrosion awareness and the publication of an easy-to-read booklet on microbial corrosion would be an effective way to do this.

It is hoped that this will help to emphasise the message that the old adage 'prevention is better than cure' is very apposite to microbial corrosion.

References

1. Duncon J. Crombie, et al. Corrosion control in crude oil distillation units processing, June 1975.
2. Z.A. Foroulis, Dipl, MSch E, Met Eng. Sc D Causes, Mechanisms and prevention of internal corrosion in storage tanks. Exxon Research and Engineering Co, Forkham. Co. Florham Park, N.Y.
3. Department of Industry. 'Corrosion prevention directory', London HMSO, 1978.
4. Donald. S. Workerley, Microbial Corrosion in UK Industry, Chemistry & Industry J. 6 Oct 1979.
5. Booth, G.H. 'Microbiological corrosion', London : Mills & Boon. 1971.
6. Miller, J.D. A. Microbial aspects of metallurgy, Aylesbury : Medical & Technical Publishing, 1971

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