CHAPTER 2

BIO CORROSION

2.1. HISTORICAL PERSPECTIVES

The first reported observation of microbial involvement in metallic corrosion was that by Garrett (1891), who attributed the corrosion of lead sheathed cables to the action of bacterial metabolites. After 2 decades, evidence was produced by Gaines (1910) for external and internal corrosion of water pipes by bacteriogenic sulphur. This was confirmed by the results of Ellis and Harder (1919) which showed the association of iron and sulfur bacteria in the deposits.

Till 1934, it remained a mystery that the corrosion of underground structure in the absence of stray electric current. Von Wolzogen Kuhr and Van der Vlugt (1934) came out with an answer for this. They proposed the first theory in microbial corrosion claiming for the bacterial depolarisation of local cathodes. The bacteria proposed to be involved being anaerobic sulfate reducers evidence for this form of corrosion started to accumulate from around the world (Starkey and Wight 1947; Hadley, 1943; Duchon and Miller 1948; Butlin et al 1949 a & b; Wanklyn and Spruit 1952) Skybalski and Olsen (1949) proposed a mechanism for the aerobic microbial corrosion for the formation of oxygen concentration cells by micro organisms through tubercle formation and it was complimented by the latter work of Uhlig (1953).

In the 1970's number of biologically induced corrosion failures of equipments (Hills, 1971) especially on the corrosion in tanks of aluminium alloys (Parberry, 1968) were reported. The only problem for reviewers of MIC is that the papers in this field are widely scattered throughout the world in many journals (Iverson, 1987).
However, with in the last few years, this situation seems to be changing. Organisation of several conferences exclusively on MIC research like 1st and 2nd International conferences on microbially induced corrosion held at England and United States respectively (1983 and 1985), Argentine - US workshop on biodeterioration with emphasis on microbial corrosion (1986), NACE's International conference on biologically induced corrosion (1985), First European Federation of Corrosion workshop on microbial corrosion conducted at Portugal (1988) and 5th European congress on biotechnology held at Copenhagen (1990) reflects the advancement of this subject. Occasionally papers on biocorrosion have also been presented at International Congress on Metallic corrosion (Now ICC) and International Congress on Marine Corrosion and Fouling (ICMC & F).

2.2. MICROBIAL CORROSION

Microbial corrosion is one of many forms of corrosion, which contributes substantial losses to the economy and pollution which requires some knowledge in the fields of chemistry, metallurgy, microbiology and biochemistry. As already stated, micro organisms can induce or influence the corrosion process by direct or indirect way (by virtue of their metabolites). While speaking about energy sources, natural habitats, in general are oligotrophic in nature and offer only a poor nutrient media (Costerton and Lashen, 1984; Gaylarde and Jhonston 1980, Marshall, 1985) for the growth and metabolism of microbes. This is true especially in the case of sea water.

This factor plays a significant role in microfouling on solid surfaces as the extent of nutrient absorption on the substrates is directly proportional to their electronegativity (Sechler and Gunderson, 1972). The degree of free oxygen availability indicates the type of MIC to certain extent. Under aerobic conditions, aerobes (which need oxygen as terminal electron acceptors) and facultative anaerobes (that can grow in the presence or absence of oxygen) can dominate. Environments
devoid of oxygen can support prolific growth of anaerobic forms and facultative anaerobes.

Generally, in oxygen rich environments, aerobes settle first and the dramatic appearance of anaerobes beneath the aerobic film is a very common phenomenon (Costerton et al; 1988). Anaerobes use lactate, malate or sulfate as terminal electron acceptors instead of oxygen. Literature of the past revealed that the anaerobic bacteria may be killed even by the traces of oxygen (Tatnall, 1985). This point itself deserves for debate and there are several claims for the possibility of micro aerophilic existence of SRB, which are conventionally regarded as obligator anaerobes (Hamilton, 1985, Hardy, 1981, Hardy et al 1981, 1984).

The role of micro organisms in metallic corrosion has been well discussed by Miller (1981), Tiller (1982, 1983), Iverson (1987), Dexter (1988) and Videla (1990). Corrosion of metals by micro organism is mainly associated with two genera of bacteria, the aerobic Thiobacillus and the anaerobic Desulfovibrio (Obuekwe, 1980). Both of them are sulfur metabolizing bacteria, Desulfovibrio Spp. being the sulfate reducers and Thiobacillus thioxidants are mainly concerned with sulfur oxidation as well as sulfuric acid production. Another species of Thiobacillus, Ferroxidans oxidize iron from ferrous to ferric state, and their role in mineral leaching is well documented and recognised as early as 1940s (Colmer and Hinkle as reported by Woods and rawlings, 1989).

A number of bibliographies (Lee, 1963; Metals Society, 1983; Biodeterioration centre - Common Wealth Mycological Institute, 1981) and Booklets in various languages (Kucera, Swedish, 1980; Chantereau, French, 1981; Videla, Portuguese 1981; Videla and Salvarezza, Spanish, 1984; Pope et al English 1984) published indicate a good start in the recognition of this menace. General reviews of microbial

2.3. MICROFOULING

Bacterial corrosion, to occur immediate just a position of the bacteria to the metal surface is necessary (Costerton et al 1988). Bacteria attack over any material immersed in the oceans with in a matter of hours (Zobell, 1943). The attachment is influenced by many physico-chemical and biological factors like nutrients (Sechler and Gunderson, 1972), surface charges, texture of the immersed metal, angles of exposure and magnitude of the micro flora in the environment (Fletcher, 1977). Microfouling at the initial state is temporary or reversible (Marshall 1971) and is influenced by various attractive forces (Marshall 1985). and the production of exopolymeric substances (EPS) by bacteria (Busscher and Weerkamp, 1987). Adsorption is initially diffusion controlled and depends upon the adsorption or loading capacity of the adsorbate (Daniels, 1980).

In natural environments occurrence of multiflier mixed biofilm consortia is very common, where the innermost tier is constituted by anaerobics while tiers are composed of aerobic species (Sanders, 1988).

2.4. STRUCTURE AND FUNCTION OF THE BIOFILM

In the early stages of biofilm development, the nature of the biofilm changes as the first group of microbes colonise, produce exopolymer and thereby affecting the micro environment at the surface (Manszalek et al 1979).

The initial rate of cell attachment is dictated by the bacterial concentration (Fletcher, 1977; Characklis, 1973) in the bulk phase which is partial in pattern.
other words, the attachment is considered to be random (Characklis, 1981). Thereafter, it becomes nutrient driven rather than culture concentration.

SEM studies on direct observation of a range of habitats show a common response of surface production of exopolysaccharide by bacteria (Costerton et al 1985). Normally occurring succeeding event is growth through cell division of the biofilm bacteria within the glycocalyx resulting in the proliferation of micro colonies. A mat biofilm formation is assisted by glycocalyx production, which binds the bacteria to each other and to the surface. The film traps inorganic and organic matter, microbial products and other microbes, which join to form complex consortia protected within the glycocalyx. Such complex consortia of bacterial aggregation, where the coexistence of 23 bacterial species has been reported. Characklis and Cooksey (1983) has summarised that in the initial phase of attachment, when the immersed surfaces which are rich in nutrients, the chemoheterotrophic sp such as Pseudomonas sp (that need relatively high concentration of nutrients) dominate and the successor being oligotrophs. Besides being acting as a nutrient sink, biofilm society is also helpful in protecting the organisms from many antimicrobial agents (Govan and Fyte, 1978; Ruseska et al 1982; Nickel et al., 1985).

The fact that the microorganisms are attracted to surfaces in response to their ability to concentrate organic materials, stems from the observation of Zobell (1943) who has reported that stimulation of bacterial growth rate in an oligotrophic environment is possible on a glass surface. Scheler and Gunderson (1972) suggested that adsorption of organic matter on surfaces is dependent on their electro-negativity. Stimulation of the rate of ethanol degradation by starved SRB cultures by introducing clay particles (Lanbrock and Geerligs, 1983) and a 20 to 25% increase in the nitrite oxidation rates of a nitrobacter sp. After attachment on glass or anion exchange can be quoted as examples of surface stimulation of activity and respiration was infact decreased (Gordon et al 1983). Bright and Fletcher (1983) studied the effect of
adsorption of a marine Pseudomonas sp. to a range of plastic surfaces and concluded that the nature of the effect depended upon the substratum, the amino acids and its concentration. Assimilation of amino acid by fouled bacteria was found to be greater than the planktonic bacteria.

Characklis (1981) has summarized that biofilm formation is a combined function of physical, chemical and biological components. The physical factors include biofilm volume and mass as well as diffusion of gases and nutrients. The chemical factors are influenced by the inorganic and organic components of surrounding aqueous phase. The biological components are principally the macro organisms themselves, which are able to colonize a surface and this alter conditions in and around the surface. He concluded that the largest influence on the biofilm development is its microbial composition as microbial growth and the growth products alter the physical and chemical properties of the biofilm.

An industrial operation contains numerous environments where corrosion and fouling processes are potentially troublesome in storage water tanks, waste water treatment facilities, filters and piping. Microbial fouling and corrosion also occur on ship hulls, reverse osmosis membranes, porous media (eg. Groundwater or oil bearing formation) ion exchangers (HC.Flemming, 1987), drinking water distribution systems (W.G.Characklis, 1988).

Biofouling frequently occurs in conjunction with other types of fouling including crystalline or precipitation fouling (eg. Scaling) and particulate fouling (frequently due to sedimentation). Microbial activity has been found in calcareous deposits, tubercules and in deposits of particulate material resulting from sedimentation or adsorption. Increased corrosion rates of metals are frequently reported in these circumstances.
A recirculating cooling tower system provides an example of a plant environment in which fouling and corrosion can occur. The evaporative losses of water results in a salt concentration increase which increases nutrient concentration. The hydraulic residence time, water temperature and surface area - to volume are all relatively high. As a consequence, microbial growth rates and cell numbers are very high.

If the material is wooden, its degradation rate can be significant due to microbial degradation (fungi) or measures to control microbial activity (chloride). In heat exchangers, scaling (under certain conditions) and microbial film development on the tubes obstructs flow of cooling water which can increase heat transfer resistance and (metal) corrosion rates.

2.5. PROBLEMS CAUSED BY FOULING

Fouling by biofilms impairs the performance of process equipment. They can form on any surface in contact with a process fluid. The economic consequences of fouling are the essential reason for industrial interest in the fouling of operating equipment. To assess the importance of a fouling situation, the economic and energy penalties arising from the operation of equipment subject to fouling must be considered.

1. Energy losses due to increased fluid frictional resistance (e.g. in pipelines, on ship hulls and propellers, and in porous media such as oil and water wells or filters and increased heat transfer resistance e.g. power plant condensers and process heat exchangers).

2. Increased capital costs for excess equipment capacity (e.g. excess surface area in heat exchangers) to account for fouling. At a Canadian power plant site, biofouling decreased heat transfer rate in a condenser by 30% over a two month...
period (Characklis, 1984). The Plant design had allowed for a 15% decrease due to fouling.

3. Increased capital costs for premature replacement of equipment experiencing severe under deposit corrosion. Recently, a nuclear power plant had to replace a condenser after approximately 6 years operation because of severe corrosion attributed partially to microbial activity. The condenser had a design lifetime of approximately 20 years.

4. Unscheduled turnarounds or downtime, resulting in loss of production, to clean equipment which fouled at an unanticipated rate. Downtime can cost a power plant as much as 1 million per day because they must purchase the power from elsewhere to serve their customers. In oil production, downtime relates directly to the amount of product being shipped which could extend to $10 million per day.

5. Quality control problems resulting from fouling in heat exchanger equipment or fouling or product stream (eg. sliming of paper mills or rolled steel).

6. Safety problems also arise due to fouling. Fouling of service water systems in nuclear power plants is a major concern because it reduces the heat transfer capacity available during an emergency or during an accident. Fouling in drinking water distribution systems may lead to high concentrations of microbes in the drinking water which potentially affect public health. Deaths due to Legionnaires disease has been attributed in several instances due to fouling in cooling towers.

The anticipated presence of significant fouling can alter the size and other design features of operating equipment. The operation of equipment subject to fouling is constrained by the need to formulate economically justifiable cleaning schedules and internal treatment programme.
An estimate of the economic consequences of fouling was presented by Pritchard for fouling in Britain and suggested the cost was between $600-1000 million per year (about 0.5% of the British 1976 GNP). Petroleum refining in the non-communist countries, the total cost of fouling is $4.4 billion per year. The costs are bound to increase with increasing fuel and material in United States to billions of dollars annually (Lund and Sandhu, 1981).

In industrial equipment, fouling of surfaces can be the main cause of progressive reduction in performance and efficiency. Accumulation of slime, dirt, and debris, in the industrial environment rarely causes concern and is the cause for the limited attention focused on fouling in the past. However, the cost of problems related to fouling are significant and must be emphasized to designers and operators of the equipment.

2.6. MICROBIOLOGICALLY INDUCED CORROSION (MIC)

Microorganisms, in habitants of all natural environments, influence corrosion phenomenon either directly by intruding into the electrochemical reactions or indirectly by virtue of their metabolic products. However, microbiologically induced corrosion (MIC) is not a new form of corrosion, but provides a new pathway to an already existing process (Booth, 1971).

Microbes can induce corrosion by creating differential aeration or concentration cells (Miller et al 1964), pH (Tiller 1982), synthesizing or depleting oxygen (Chidambaram and Balakrishnan 1989) utilizing cathodic hydrogen (Von Wolzogen kubr and Vander Vlagt, 1934) or by producing hydrogen removing metallic atoms from metals oxidizing or reducing corrosion inhibitors (Iverson, 1972), setting up of galvanic cells (King and Miller, 1971), disturbing or peeling of protective organic coatings (Harris, 1960), and by their metabolic products (Iverson, 1984). Inspite of the initial awareness existed about MIC, seriousness of this one race is
slowly being recognized throughout the world during the past few decades which is well evidenced by the ever increasing case histories (Sequeira, 1988).

2.7. MECHANISMS OF MICROBIOLOGICALLY INFLUENCED CORROSION

2.7.1. Anaerobic Bacterial Corrosion

By the down of the century, removal of cathodic depolarising oxygen, from the buried soil was thought to be ideal for corrosion prevention. But Von Wolzogen Kuhr and Van der Vlugt (1934) bitterly attacked this view with their historical finding on the existence and activity of SRB under anaerobic conditions as well as their role in metallic corrosion, which was considered to be the most important corrosion processes in nature (Hadley, 1948). Since that time, there has been an ever increasing awareness of the extent and importance of microbial corrosion in general, and of anaerobic corrosion in particular (Hamilton, 1985), which results in the outburst of laboratory investigation using SRB. But although till 1949, it seems like that only a few pure culture were available in the world (Butlin, et al. 1949a) and not all those were as pure as their properties believed (Postgate, 1984), it is quite evident that their experimentation was certainly with SRB, whether they were pure or mixed cultures.

SRB the important should be mentioned anaerobic corrosion scenario, should be mentioned here for their nature of adaptation or tolerance to a variety of contrasting environmental conditions like occurrence at and below 500 meters depth in oil wells (Bastin, 1926) and at Marianas Trench (Anon, 1976), tolerance over oxygen shocks (Hardy and Hamilton, 1981; Saleh, 1983) ability to adjust from fresh water to seawater and vice vera (Postgate, 1975) as well as for their ability to use wide variety of compounds as terminal electron acceptors (Postgate, 1984). These adaptations enabled this specialized group of bacteria in maintaining their key role in the scenario of anaerobic corrosion.
2.7.2. Cathodic depolarisation - By Bacteria/Bacterial Activity

Probably Gains (1910) was the first to recognise that the bacterial involvement might be a cause for the corrosion of steel and iron under anaerobic environments. However, a logical mechanism for the corrosion caused by sulfate reducers was first provided by the classical theory (Van Wolzogen Kuhr). The theory proposed has the following sequence of events as the mechanism of anaerobic bacterial corrosion.

- **Ionisation of water**: $8\text{H}_2\text{O} \rightarrow 8\text{H}^+ + 8\text{OH}^-$ (1)
- **Anodic Reaction**: $4\text{Fe} \rightarrow 4\text{Fe}^{2+} + 8\text{e}^-$ (2)
- **Cathodic Reaction**: $8\text{H}^+ + 8\text{e}^- \rightarrow 8\text{H}$ (3)
- **Cathodic polarisation by SRB**: $\text{SO}_4^{2-} + 8\text{H} \rightarrow \text{S}^2^- + 4\text{H}_2\text{O}$ (4)
- **Corrosion Products**: $\text{Fe}^{2+} + \text{S}^2^- \rightarrow \text{FeS}$ (5)
  $3\text{Fe}^{2+} + 6\text{OH}^- \rightarrow 3\text{Fe(OH)}_2$ (6)
- **Overall reaction**: $4\text{Fe} + \text{SO}_4^{2-} + 4\text{H}_2\text{O} \rightarrow \text{FeS} + 3\text{Fe(OH)}_2 + 2\text{OH}^-$ (7)

Kuhr et al. claimed that cathode is depolarised by the metabolic oxidation of hydrogen by SRB for its characteristic sulphate reduction process.

The proposal was supported by an earlier observation that SRB posses the enzyme, hydrogenase that helps in the removal of hydrogen for reduction at sulfate (Stephenson and Stickland 1931). Lately, data in support at this theory was obtained by Starkey and Wight (1947), Butlin et al., (1952), Harvathn and Solti (1959); Iverson (1966), Booth and Tiller (1960, 1962, 1968).
2.7.3. Aerobic Bacterial Corrosion

Although SRB are the extensively studied bacteria (Stott, 1988), the role of aerobic sulfur and iron oxidizing bacteria cannot be ignored. The literature on MIC is abundant with activity of anaerobic SRB and not much information is available on the role of aerobic bacteria in the corrosion of metals (Obuekwe, 1980). The situation is changing now which is evidenced by the publication of Bondonno, et al., (1989), Hoffmann, et al., (1981), Bartels (1989), Tiller (1982). However at any extent, this cannot be compared with the wealth of publications on SRB. In a natural ecological nickel, the aerobic sp. from the outer tier of the film provide complete / partially anaerobic environment, where SRB thrive actively. Besides being helpful in anaerobic bacterial corrosion to proceed, thiobacilli themselves play a key role in corrosion.

Romanoff (1945) reported the tendency of some soils to change towards acidic pH when aerated. Kulman (1953) attributed this change to the proliferation of aerobic sulfur oxidizing bacteria. Iverson (1987) considered acids as the most corrosive metabolite produced by microbes. The acids by supplying an excess of hydrogen ions, provide an excellent electron 'sink'. The formation of \( \text{H}_2\text{SO}_4 \) of biological origin, constitute classical example of this mechanism, (Starkey 1950).

Chemistry of sulphuric acid production by thiobacilli and the steps involved in sulfur oxidation has been studied. The chemistry of acid production by thiobacilli was discussed by Booth (1971), Roy and Tandinger (1970), and also by Cragnolino and Tuovinen (1984).

All the possible thiobacilli induced sulphuric acid generation mechanisms reveal many inorganic compounds are susceptible to thiobacilli induced oxidation. In the biological path way of oxidation, the various oxidative steps are mediated by
specific enzymes with coupling to an electron transport system, where oxygen is reduced to water as terminal reaction, viz;

\[ \text{O}_2 + 4\text{H}^+ + 4e^- \rightarrow 2\text{H}_2\text{O} \]

Regarding various steps involved in one of the pathways of sulfide, elemental sulfur and sulfo-oxy anions oxidation are well discussed by Kelly, (1982).

In the above non-stoichiometric presentation of the microbial oxidation at inorganic sulfur compounds, several enzymatic reactions, especially those associated with the oxidation of sulfide, polysulfide, and elemental sulfur, need to be characterized (Kelly, 1982).

Production of sulfur oxyanions as metastable intermediates by thiobacilli has no significant role to play in aerobic MIC, due to their unstable nature in oxidative environments. However, Murphy et al (1973) showed that some of the intermediates like \( \text{S}_4\text{O}_6^{2-} \) may accumulate until the substrate is completely oxidized, but the ensuing oxidation leads to the formation of sulfuric acid. Tuovinen and Kelly (1974) claimed for the accumulation of sulfur as a result of thiobacilli induced disproportionation of \( \text{S}_2\text{O}_3^{2-} \), if a stress factor such as, inadequate toxic metal ions or excessive acidity is imposed on the bacteria.

Although the factor like inadequate aeration plays a role in the disproportion of \( \text{S}_2\text{O}_3^{2-} \) some thiobacilli were reported to oxidize sulfur compounds under anaerobic conditions. For instance, sulfur compounds can be oxidized by T. denitrificans and T. trioparces, using nitrate or nitrite as an electron acceptor.

Direct works on thiobacilli induced corrosion are much limited. The available works also interpret the rates of corrosion alone rather than the actual mechanisms involved (Bondonnvo, et al, 1989).
Consideration on the physiology of Thiobacillus sp. indicate that this organisms may not be active in many soils. However, Parker and Prisk (1953) as well as Starkey (1956), described several species of thiobacillus which will reduce soil pH to 6.0. Horvath (1962) established much higher weight loss in the presence of thiobacillli than in their absence, and observed a rapid fall in solution pH correspond to a shift in redox potential of the metal in negative direction. The same work correlated the increased corrosion rate to the decreased pH and cathodic shift in the potential of the metal.

2.7.4. Iron Oxidation by T.Ferrooxidants

A wide spectrum of studies explored the possibility of using T.ferrooxidants, the bacteria that oxidizes iron from ferrous to ferric state in addition to its sulfur oxidation, to extract iron from (Ashmead, 1955; Rogoff et al 1961; Silverman et al 1951, 1963) oxidative dissolution of FeS$_2$ in coal (Lethan et al 1953). The mechanism of FeS$_2$ removal proposed by Hoffmann et al., (1981) is given below.

$$\text{FeS}_2 + \frac{7}{2} \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2 \text{SO}_4^{2-} + 2\text{H}^+ \hspace{1cm} (1)$$

$$\text{Fe}^{2+} + \frac{1}{4} \text{O}_2 + \text{H}^+ \rightarrow \text{Fe}^{3+} + \frac{1}{2} \text{H}_2\text{O} \hspace{1cm} (2)$$

$$\text{FeS}_2 + 14\text{Fe}^{3+} + 8 \text{H}_2\text{O} \rightarrow 15 \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16 \text{H}^+ \hspace{1cm} (3)$$

Equation (1) is linearly dependent on equations 2 and 3 and can be used to represent overall reaction stiochiometry for kinetic purposes.

Singer et al (1970) proposed that equation (2) is catalyzed by T.ferrooxidants through the results of their experimentation on pyrite dissolution in the presence and absence of T.ferrooxidants. The oxidized iron will either oxidize sulfur compounds to form H$_2$SO$_4$ or induce anodic reaction directly.
On the other hand, works on bio metallurgical aspects like bacterial leaching or biochemical and microbiological aspects are satisfactorily high. Mostly, corrosion by oxidation of iron was strictly attributed to the genera Gallionella, Grenothrix and Sphaerotilus but not to T. ferrooxidants in the past (Bondonvño et al., 1989).

2.7.5. Other Corrosion Mechanisms - Producing Differential Aeration Cells.

Almost all the microbes whether produce aggressive metabolites or not, can induce corrosion by creating differential aeration cells through fouling. In other wards, they deplete a nutrient source thus producing an aggressive environment (Tiller, 1982). The formation of differential aeration cell results through the uptake of oxygen by the microbial colony leading to the depletion of oxygen under such biofilm. The poorly aerated surface becomes the anode of the local corrosion cell (which can also support anaerobic bacterial growth) while the better aerated regions, away from the deposits, provide balancing the cathodic reaction.

2.7.6. Tubercle Formation

Tubercles composed of ferric hydroxide formed by iron bacteria, by virtue of their ability to oxidize iron from ferrous to ferric state, result in the creation of the so called oxygen concentration cells. The area beneath the tubercles are prevented from contact with oxygen dissolved in water and hence acts as anode, as in the former case. The structure and composition of the tubercle was described by Ainsworth et al (1978).

2.7.7. Corrosion due to Bacteriogenic Sulfuric Acid

The mechanism is interpreted as the on set of septicity of concrete sewers or activity of sulfate reducers leading to the release of H₂S which adsorb on the wall of
the sewers and from where it can be oxidized to sulfuric acid by bacterial action. Besides concrete sewers or cooling towers, a number of case histories on similar form of attack were well documented. For instance, temples of Cambodia (Pochon and Jaton, 1968) and Parthenon in Greece, Ferrous pipeline (Booth 1971).

2.8. CORROSION INHIBITION BY BACTERIA

Pederson et al (1990) have suggested that protection caused by Cellular Metabolic activity, including a decrease of oxygen content. Soracco et al (1984) have found that in presence of bacterial film on mild steel the corrosion rate is less than under sterile conditions. Ford et al (1988) detected that some bacteria reduce the corrosion rate. Pedersen and Hermansson (1988) established that the corrosive ability of Pseudomonas species and Serratia marcescens (EF 190) can be dominated by protective factors under certain conditions. Hernandez et al (1994) found that the inhibition effect of bacteria disappeared with time. Bacterial cell walls are negatively charged and it improves the passivity of metal. One of the most interesting studies by Scotta et al 1998 suggest that (Protein polymers) enzymes play an important role in inhibition of corrosion. Black et al (1988) observed that the metal - binding exopolymers from iron and manganese depositing bacteria improved the passivation by particular Pseudomicrobium sp.
REFERENCES

eposits in iron mains, water distribution system - Maintenance of water quality
and pipeline integrity, Oxford paper No.8, Water Research Centre,
Medmenham.

2. Anon (1976). The role of bacteria in the corrosion of oil field equipments,
Technical publication committee release No.3, NACE Tx.

waters, Colliery Guardiana, 190, 694-698.


for investigation and quantification of bacterial leaching by Thiobacillus
ferroxidans, biotechnol. Bioengg., 33, 1196-1204.

CE/1, Mills Booth, London.


and Thiobacillus biofilms on the corrosion of electroless nickel plated M.S.,

472.

attached and free living populations of a marine pseudomonas sp., Microb.


Houston. Tx, 1988, pp.1-8, 94.


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