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BIOLOGICAL CORROSION AT NAVAL SHORE FACILITIES

(WITH APPENDED BIBLIOGRAPHY ON BIOLOGICAL CORROSION)

By

Harold P. Vind, Ph. D., and Mary Jane Noonan

20 July 1966

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TN-631

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ABSTRACT

Each year the Navy spends millions of dollars for the maintenance, repair, and replacement of structures and utilities damaged by corrosion. Expenditures resulting from the corrosion of steel waterfront structures in the regions of periodic wetting by sea water are especially great.

Considerable evidence indicates that bacteria and other organisms frequently initiate or accelerate corrosion of metals. Microorganisms accelerate corrosion by producing hydrogen sulfide or acids, both of which are highly corrosive to iron and steel. Thiobacillus thiooxidans, the bacteria which convert sulfides or free sulfur to sulfuric acid, may cause the extremely rapid corrosion of steel waterfront structures in the intertidal zone; but this has not been established by experimental evidence.

Experiments were undertaken at the U. S. Naval Civil Engineering Laboratory to ascertain if the presence of microorganisms is necessary for corrosion to occur. It was shown that, in aerated sea water, iron corrodes fairly rapidly whether or not microorganisms are present; but that, in sea water, from which oxygen is excluded, iron rusts very slowly unless sulfate-reducing bacteria or their metabolic by-product, hydrogen sulfide, is present. To induce rapid anaerobic corrosion, the bacteria must be supplied with carbohydrates or other nutrients. Anaerobic conditions and bacterial nutrients might both be found in the layer of slime that accumulates on the surfaces of structures placed in the ocean.

Another experimental finding at the U. S. Naval Civil Engineering Laboratory was that the carbonic anhydrase inhibitor, acetazolamide, is an effective inhibitor of sea water corrosion.

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INTRODUCTION AND STATEMENT OF PROBLEM

Annually the Navy spends millions of dollars for the maintenance, repair, and replacement of structures and utilities damaged by corrosion.¹ An understanding of the causes of corrosion and means of preventing corrosion is thus of paramount concern to the Naval Facilities Engineering Command. Considerable evidence indicates that bacteria and other organisms frequently initiate or accelerate corrosion. A paramount question is whether organisms play a major or an insignificant role in the corrosion of structures maintained by the Naval Facilities Engineering Command.

CORROSION PROBLEMS AT NAVAL SHORE FACILITIES

The extent and severity of corrosion of structures at Naval Shore Activities vary with the location of the structures.¹ Metal structures that are buried, situated above ground, or located on a waterfront each exhibit unique patterns of corrosion and each requires different maintenance and corrosion prevention measures. Some of the corrosion problems have been satisfactorily controlled but others remain unsolved.

Corrosion of Underground Structures

Corrosion of Underground structures or utilities continue to impose a serious maintenance problem at some Naval activities.² Steam condensate return lines and heat distribution systems located below the water table constitute a major problem, though corrosion of all buried structures is rapidly being reduced by better drainage in the soil, by cathodic protection, and by the use of substitute materials^{3,4} such as epoxy-glass and polyvinyl chloride.

Experiences in the Gulf Naval Division illustrate the effectiveness of cathodic protection in the prevention of underground corrosion. In 1953, several buried fuel tanks in that division were found to be severely corroded even though the exteriors of the tanks had been covered with an asphaltic paint prior to installation. In 1953 and 1954, cathodic protection equipment of the impressed voltage type was installed on all of the buried fuel and water tanks in the division at an installation cost of approximately one to ten percent of the cost of the tanks. Measurements made in 1964 indicate that very little

corrosion has occurred since the cathodic protection equipment was installed. Buried fuel and water lines in the Gulf Naval Division have a long history and, prior to 1955, frequent replacement or repair of buried pipes was necessary. At the Dallas Naval Station, for example, the monthly cost of repairing buried fuel and water lines was in excess of one thousand dollars. In 1955, cathodic protection equipment of the impressed voltage type was installed on all buried pipes, and the need for repair since has been negligible.

Comparable success in prevention of underground corrosion has been achieved through the use of plastic pipe and the construction of concrete drainage trenches. Thus, although bacteria may play a significant role in the corrosion of underground structures and utilities, their predatory activities can be controlled.

Corrosion of Above Ground Structures

Since the corrosion of metal structures above ground cannot be arrested by cathodic protection, corrugated steel shops, warehouses, coal bunkers, and similar structures still present some maintenance problems (Figure 1). Painting is the sole effective maintenance procedure for protecting such buildings or structures. Primers that prolong the life of overcoated paint films applied to metal have been developed; yet, for various reasons, the paint still fails. In many instances, rusting of the underlying metal appears to precede the peeling of the paint, and, to date the importance of bacteria in this sequence of events is not known. Frequently, corrosion of corrugated steel structures occurs where wood contacts metal, a problem especially severe in tropical climates. Wood-rotting fungi that produce organic acids might be causative agents, but this too has not yet been established. Compared to the problems faced in the maintenance of buried iron pipes and steel waterfront structures, those faced in the maintenance of metal buildings above ground are relatively minor.

Corrosion of Waterfront Structures

The most serious corrosion problems at Naval activities occur on the waterfront. In every Naval Division, at least one major waterfront structure is failing or has recently failed and been replaced as a consequence of the corrosion of structural steel. Typically, the structures involved are fifteen to twenty years old.

As yet, measures preventing corrosion of steel waterfront structures have not been as successful as are those used with buried tanks and pipes. Cathodic protection does not prevent corrosion of

portions of steel structures extending above or suspended above the water line, the region of most severe corrosion, and, even though effective, cathodic protection is not widely used to prevent the corrosion of the submerged portions of steel waterfront structures. Likewise, the use of protective coatings to prevent the corrosion of waterfront structures has met with but limited success.

Corrosion of steel bulkheads, underdeck piping, and other waterfront structures, such as electric light poles (Figure 2), is rapid at most harbors, although exceptions exist. At Quonset Point, Rhode Island, for example, a steel bulkhead less than twenty years old is failing; whereas across the bay at Newport, Rhode Island, a steel bulkhead forty years old remains in good condition. Even an experimental concrete jacket failed to halt the corrosion at Quonset Point. One explanation for the differences in service life of the bulkheads in the two harbors is the degree of pollution of the water. At Quonset Point, the harbor water is said to be highly polluted; whereas, at Newport, tidal action brings clean water of the deep offshore channel to the harbor. Another possible cause for the differences cited is that on several occasions, oil has been accidentally spilled near the bulkhead in the Newport Harbor, thereby coating the bulkhead with a thin film of oil. (The age-old household method to prevent rusting by a periodic application of a thin coat of oil might save the Navy considerable sums.)

A twenty-year old bulkhead or sea wall several miles long at the Naval Air Station, Floyd Bennet Field, New York, is in an advanced stage of deterioration. For several hours before and after low tide, most of the structure is completely dry. A large section, shown in Figure 3, is so badly perforated in the mean low tide zone that it no longer retains the earthen fill. Other sections, such as that shown in Figure 4, still retain the earthen fill, but they are in need of extensive repair.

During World War I, an extensive wood-piling bulkhead was constructed at the U. S. Naval Base, Norfolk, Virginia. During World War II, the base was modernized and concrete-decked sheet steel bulkheads were installed. The sheet steel piling was driven a short distance in front of the old wooden bulkhead (which was not removed) and an earthen fill was placed between. By 1950 it was already apparent that the new bulkhead was rapidly deteriorating (Figure 5). By 1959, the steel bulkhead was perforated at many spots (Figure 6) and large sections of the steel wale had fallen off. In late 1959, during Hurricane Donna, the steel bulkhead collapsed and released the fill between the old and the new bulkheads. Fortunately, the older wooden bulkhead remained intact and prevented more serious damage. The two bulkheads have since been faced with a third bulkhead of concrete and steel. Should that fail also, the old wooden bulkhead, remaining intact a few feet behind, will again serve its intended function.

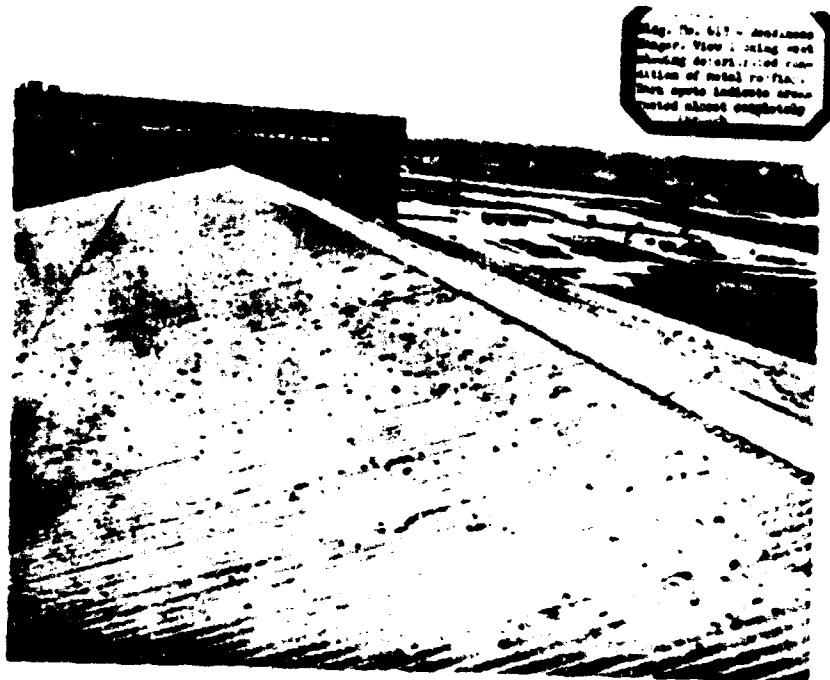


Figure 1. Metal roof perforated by corrosion.
(Naval Station, Newfoundland, 1962)



Figure 2. Metal light pole exposed to ocean spray.
(Naval Shipyard, Norfolk, 1958)



Photograph 15. "C" Section Sta. 1340
to 2147

Figure 3. Loss of earthen fill by damaged bulkhead.
(Naval Air Station, New York, 1963)



Photograph 16. "C" Section Sta. 1340
to 2147

Figure 4. Corroding bulkhead in need of repair.
(Naval Air Station, New York, 1963)

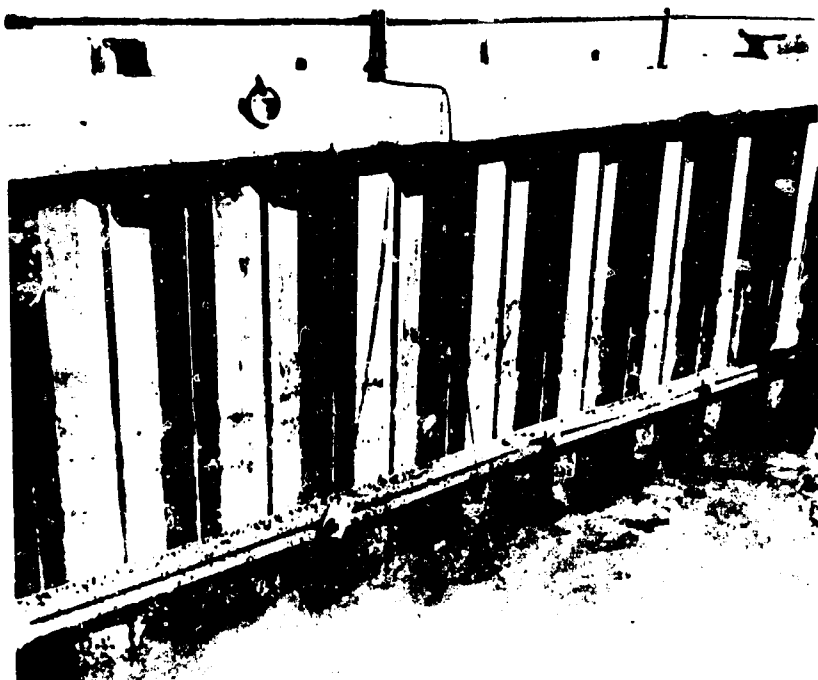


Figure 5. Bulkhead 3 years before hurricane Donna.
(Naval Air Station, Norfolk, 1956)

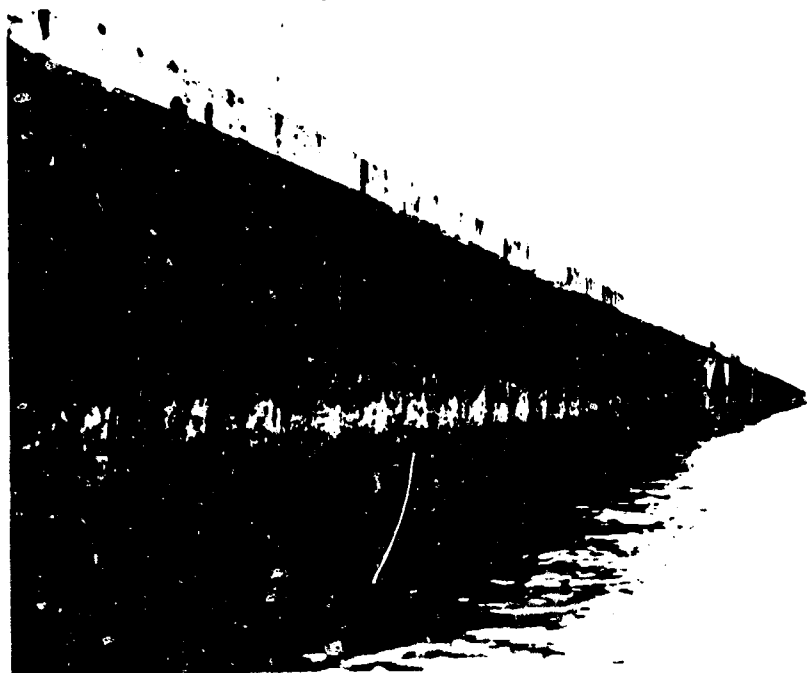


Figure 6. Bulkhead immediately prior to hurricane.
(Naval Air Station, Norfolk, 1959)

In recent years, steel H-piles have replaced wooden piles in the piers and wharves at Naval Activities on the Gulf Coast. The piles corrode even though they are heavily covered with a bitumastic coating before they are driven. Corrosion occurs primarily at, or just above, the water line and occasionally at, or just above, the mud line. Various splash zone coatings have been employed to prevent this corrosion; but at the breaks or cracks that eventually develop in the coatings, corrosion occurs more rapidly than if there were no coatings. Steel piles of the Galveston pier are now being encased in concrete that extends several feet below the water line, though it is not at all certain that the concrete caps will prevent further corrosion. Similar caps did not prevent corrosion of steel piles at Quonset Point, Rhode Island, nor at the Boston Naval Shipyard. Whether the steel piles of the piers at the various gulf ports will last sufficiently longer than wooden piles to justify their higher cost remains to be seen.

Typical of the larger steel waterfront structures to succumb to corrosion are two breakwaters at Corpus Christi, Texas. The breakwaters (Figures 7 and 8), constructed of huge steel cylinders, and decked with concrete are but fifteen years old and are at present riddled with holes at the water line. One will be abandoned and the other will, if possible, be repaired.

Corrosion of Mid Ocean and Undersea Structures

Presently, Naval Facilities Engineering Command (NAVFAC) is primarily engaged with the design, construction and maintenance of structures on the shore of the oceans. In the future, NAVFAC may assume a primary responsibility for the design, construction, and maintenance of floating bases in mid-ocean and underwater bases or structures both on the continental shelves and in the deep ocean. NAVFAC activities can anticipate corrosion problems in these new environments.

ORGANISMS THAT INFLUENCE THE CORROSION OF METALS

It is well established that the immediate chemical reaction called corrosion is an electrochemical reaction rather than biochemical.⁸ Microorganisms, however, release chemicals into the immediate environment of the iron, or remove them from this environment thereby causing changes in the corrosion rate. The discharge of metabolic by-products of bacteria can even cause rapid and severe corrosion to occur in an environment where corrosion would otherwise not occur at a significant rate. Because of the economic importance of corrosion to the Navy, it is well to review the ways in which various organisms are reputed to influence corrosion rates.



Figure 7. Concrete decked steel breakwater.
(Naval Air Station, Corpus Christi, 1959)

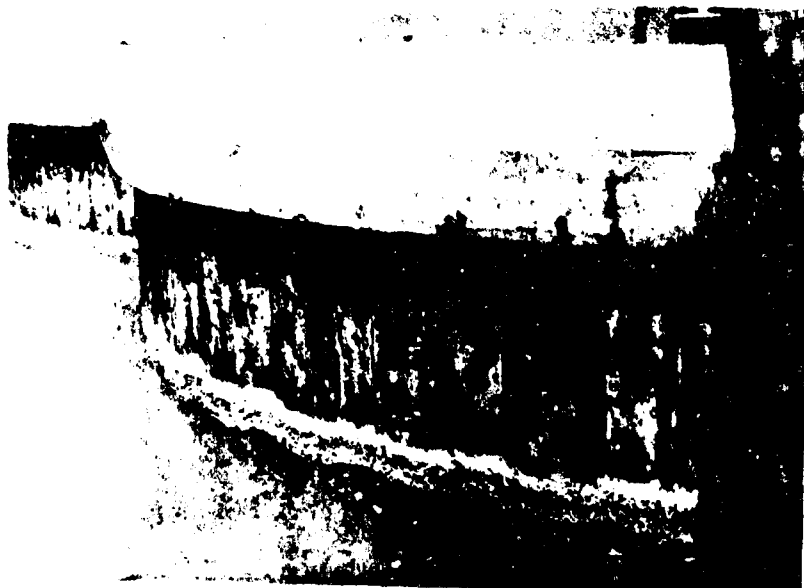


Figure 8. Corrosion of sheet piling on breakwater.
(Naval Air Station, Corpus Christi, 1959)

Organisms That Produce Hydrogen Sulfide

Hydrogen sulfide significantly accelerates the corrosion of iron, but it is volatile and somewhat unstable and does not remain long in natural waters unless produced continuously. Hence, sulfide corrosion can be attributed to the agent or processes producing hydrogen sulfide.

Some of the hydrogen sulfide found in sewage or heavily polluted waters arises from protein decomposition, but most of the hydrogen sulfide occurring in natural waters is attributable to reduction of sulfate ions by bacteria. Sulfate ions occur widely in ground and river waters, and about ten percent of the salt in sea water consists of sulfates. Bacteria capable of reducing sulfates to sulfides are widely distributed both in terrestrial and marine environments and, whenever conditions are appropriate, the bacteria produce copious quantities of hydrogen sulfide.

Most microorganisms reduce traces of sulfate sulfur to sulfhydryl or disulfhydryl sulfur when they synthesize proteins. A few highly specialized bacteria can utilize sulfate ions as hydrogen acceptors in their energy producing reactions.^{9, 10} These truly sulfate-reducing bacteria are generally classed as a single genus, but their classification is still uncertain and their nomenclature is confusing. Various names have been given to sulfate-reducing bacteria; names such as Spirillum desulfuricans, Desulfovibrio desulfuricans, Clostridium nigrificans, Desulforistella hydrocarbonastica, Vibrio desulfuricans, and Desulfovibrio aestuarii. Confusion regarding the nomenclature of sulfate-reducing bacteria, which should likely all have the same genus name, arises from the difficulty in isolating pure cultures of these organisms and from the fact that supposedly different species are interconvertible by gradual acclimatization.

Sulfate-reducing bacteria require special conditions for growth. They are in general obligate anaerobes and will thus usually grow only in the complete absence of molecular oxygen. Growth of sulfate-reducing bacteria is often initiated in the thin film of bacterial slime that forms on iron surfaces exposed in the ocean or buried in wet soil. As rusting continues, the oxygen within the bacterial slime is depleted by oxidation of the iron, thus initiating anaerobic conditions that promote growth of obligately anaerobic bacteria. Aerobic bacteria within the slime will also utilize oxygen thus creating anaerobic conditions. Once growth of sulfate-reducing bacteria begins, there is a tendency for the anaerobic region to spread because hydrogen sulfide, itself an active reducing agent, is produced.

Sulfate-reducing bacteria cannot obtain energy for their growth and activity by reducing sulfate sulfur to sulfhydryl sulfur and, in fact, they must supply considerable energy to effect the reduction. The bacteria are able, however, to more than regain this energy by oxidizing hydrogen or carbon with the oxygen released from the sulfate ions from which the sulfur atoms have been extracted. Thus sulfate-reducing bacteria not only require sulfate ions and anaerobic conditions, but a supply of food or "fuel." They are not fastidious in their food requirements and can oxidize a variety of organic substances as well as molecular hydrogen.

Organisms That Metabolize Cathodic Hydrogen

Theoretically, hydrogen is produced at cathodic sites on corroding metal and the removal of hydrogen from these sites is believed to be one of the principal rate regulating steps in the corrosion process.⁵ The belief that sulfate-reducing bacteria accelerate anaerobic corrosion by metabolizing the cathodic hydrogen is substantiated by evidence that sulfate-reducing bacteria readily metabolize molecular hydrogen.

The hydrogen acceptor in aerobic corrosion is molecular oxygen, but in anaerobic sulfide-corrosion sulfate ions are presumed to be the hydrogen acceptors. Although sulfate ions are not ordinarily capable of serving as hydrogen acceptors, it is believed that sulfate-reducing bacteria enable them to function in this capacity. It has also been suggested that methane-producing bacteria, as well as nitrate-reducing bacteria, might enable carbon dioxide molecules or nitrate ions to function as acceptors for cathodic hydrogen from corroding metal.

Hydrogen gas is slowly liberated from the surface of iron filings⁵ kept in contact with a deaerated aqueous solution of inorganic salts buffered to a pH of 6.0 - 6.5. The pH of the solution gradually rises to about 8.0 at which point the reaction slows down considerably. The hydrogen so liberated may be collected if the reaction is carried out in an inverted U-necked cylinder originally filled to capacity with the solution. As it collects, the hydrogen forces some of the solution from the mouth of the cylinder. Sulfate-reducing bacteria can then be cultivated in the cylinder, providing the solution in the cylinder contains sulfates and carbonates or bicarbonates. No energy-yielding substrate other than the hydrogen liberated by the corroding metal is required.

Growth of sulfate-reducing bacteria under the conditions cited above and the subsequent production of hydrogen sulfide are held as proof that the bacteria repolarize cathodic sites on corroding metal,

i.e., that they scavenge the thin film of nascent hydrogen adsorbed to the surface of the metal and presumed to govern its corrosion. It would seem, however, that the activity of the bacteria under the conditions cited might merely demonstrate that sulfate-reducing bacteria can utilize molecular hydrogen spontaneously liberated from corroding metal.

Whether removal of cathodic hydrogen is the role played by sulfate-reducing bacteria in the corrosion of iron is not merely an academic question. If this is their role, sulfate-reducing bacteria engaged in the production of hydrogen sulfide via the metabolism of substrates other than cathodic hydrogen would have no influence on corrosion rates; and anaerobic bacterial corrosion would proceed as rapidly in the absence as in the presence of other energy sources. Elucidation of the mechanism has, therefore, practical significance. A basic question is whether the process of hydrogen sulfide formation is itself the process accelerating corrosion, or whether the liberated hydrogen sulfide reacts with iron to accelerate its corrosion. Of course it is possible that both of the processes accelerate corrosion.

Organisms That Oxidize Sulfur to Sulfuric Acid

Hydrogen sulfide produced in an aqueous environment escapes at the surface of the liquid where it may be subsequently adsorbed onto the surfaces of structures existing in the vicinity.⁹ Some of the hydrogen sulfide reacts with air to form free sulfur, which also may be adsorbed on nearby structures. The adsorption of sulfides and free sulfur frequently occurs on the walls of sewage conduits and sewage tanks and might occur at or just above the water line on the surfaces of waterfront structures.

In an aerobic aqueous environment, sulfides and free sulfur are rapidly converted to sulfuric acid by the bacterium, Thiobacillus, of which the best known representative is Thiobacillus thiooxidans. This species is known to produce sulfuric acid with concentrations as high as ten percent.¹¹ When the acid is produced on the surfaces of metal tanks or metal sewage conduits, it accelerates their corrosion significantly. This type of corrosion is also frequently responsible for severe damage to crude-oil storage tanks and pipe lines. Acid corrosion induced by Thiobacillus thiooxidans is, under certain conditions, the most serious type of corrosion encountered.

It is a distinct possibility that the rapid and severe corrosion that usually occurs on steel waterfront structures in the region of periodic wetting is also caused by the localized production of sulfuric acid by Thiobacillus thiooxidans. This has not been substantiated,

however, and, until further investigation is pursued, one can but merely speculate on the role played by sulfuric acid-producing bacteria on the deterioration of steel waterfront structures.

Organisms That Oxidize Ferrous Iron to Ferric Iron

Many bacteria are capable of oxidizing ferrous compounds, the initial products of corrosion, to ferric compounds.¹¹ Some of the iron-oxidizing bacteria are strictly autotrophic and require no carbohydrate or other organic material for food.¹² They obtain all of the energy required for their growth and activity by oxidizing ferrous ions and synthesize the necessary organic "building blocks" of cell components by "fixing" carbon dioxide. Some of the better known species of autotrophic iron-oxidizing bacteria are Thiobacillus ferrooxidans, Gallionella ferruginea, and Ferrobacillus ferrooxidans.

When iron rusts and resulting ferrous corrosion products are oxidized to ferric compounds, iron bacteria are usually found in great numbers. Many investigations have been made of the role played by the iron bacteria in the corrosion of iron; but that role, if any, is still rather obscure. The bacteria may accelerate the oxidation of the ferrous compounds, but again they may merely be capturing the energy of a chemical reaction that is but little influenced by their presence. Ferrous ions can be oxidized to the ferric state quite readily in the absence of any bacteria and, furthermore, the oxidation of ferrous iron to ferric iron does not necessarily have a significant influence on overall corrosion rates.

Many water supplies are rich in ferrous salts, especially ferrous carbonates, which are relatively soluble in water. Iron bacteria oxidize the ferrous salts to insoluble ferric hydroxides and under suitable conditions, cause large flocculent masses of characteristic reddish-brown ferric hydroxides and oxides to accumulate in such quantities as to clog the water mains. The source of the iron, however, usually is the water and not metal pipes.

Organisms That Produce Organic Acids

Most microorganisms produce a great variety of organic acids. Molds are especially capable of producing organic acids in quantities sufficiently great to markedly increase the acidity of their environment.¹³ Aspergillus niger, Penicillium cyclopium, and numerous other species frequently attack the fabric of electrical insulation on power cables. Free acids accumulate on the surface of the exposed wire in sufficient concentrations to rapidly corrode the wire. This type of attack on electrical power lines, on coils of electric motors, and

other insulated electrical utilities and instruments is especially common in tropical areas. The organic acids produced by aerobic fungi also frequently cause the pitting and corrosion of aircraft fuel tanks and fuel storage tanks.¹⁴

The organic acids liberated by microorganisms in a marine environment probably have but little influence on the corrosion of structures below the water line. The acids are not produced in sufficient quantities to alter the pH of sea water and there is no evidence that organic acids influence corrosion by any mechanisms other than by altering the pH. Organic acids liberated by microorganisms on the surfaces of steel structures extending above the water line might, however, accumulate in concentrations great enough to significantly increase the surface acidity. Under such circumstances the organic acids would speed up corrosion considerably. The microorganisms could not produce organic acids from the metal itself but they might produce the acids from organic fouling debris attached to the surface of the structure.

Organisms That Produce Oxygen

The presence of unicellular photosynthetic organisms in the ocean is well established and in sunlight many of them liberate oxygen, one of the principal agents accelerating corrosion. Where and how extensively diatoms and other photosynthetic organisms accumulate on the surfaces of iron and steel structures immersed in the ocean has received but scant attention. These organisms might well play an important role in the corrosion of metal structures in the splash and spray zones and in the intertidal zone.

Organisms That Form Films or Layers of Fouling Growth

In the thin film of bacteria, rust, and slime that readily accumulates on the surfaces of iron structures in the ocean, the concentration of dissolved gases differs considerably from that of the surrounding water.¹⁵ Both the bacteria in the film and the iron to which it is attached remove oxygen from the water faster than it can diffuse through the film; and consequently, conditions in the film are frequently anaerobic and ideally suited for the growth of hydrogen sulfide-forming bacteria. Anaerobic corrosion can, therefore, occur even in well-oxygenated areas of the ocean. Iron buoy chains, for example, are frequently covered with heavy black deposits having the tell-tale odor of hydrogen sulfide. Deep craters and grooves are found on the chains when the black deposits are removed. The adhering film of bacteria and slime can, however, serve to merely lower the concentration of oxygen, and not create anaerobic conditions. In such instances, the bacterial film probably retards corrosion significantly.

Larger fouling organisms such as barnacles and sea urchins also influence corrosion¹⁶ and are especially active in destroying protective coatings applied to metal to retard corrosion.¹⁷ Another mechanism whereby the larger fouling organisms influence corrosion is in the creation of so-called "oxygen concentration cells." The surface of the metal under a barnacle or other macro-fouling organisms soon becomes anaerobic, whereas surrounding areas are exposed to more abundant supplies of oxygen. In consequence of the different oxygen concentrations, a galvanic concentration cell is formed and the electrical potentials set up in the metal induce corrosion and pitting to occur under the fouling organism. The effect is more to concentrate corrosion at localized areas than to increase the overall corrosion.

Fouling organisms have also been known to actively "bore"¹⁸ into metal. For example, sea urchins may destroy steel piling. With their chisel-like "teeth," more commonly used to browse on sea weed, sea urchins continuously scrape the rust from the surface of steel piling leaving the bare metal ever exposed to the corroding action of sea water. Teredo and pholads have also been known to bore into lead sheaths of underwater cables.¹⁹

To date, the important initial stage of fouling, the formation of a "primary film"²⁰ of dissolved organic material, bacteria, diatoms, algae and other marine microorganisms, has received but scant attention. The formation of the primary film is not only the first step in the process of fouling, but it is the first step in the process of bacterial corrosion of metals and in the bacterial decomposition of protective coatings. Attachment of microorganisms is also the primary step in terrestrial processes of biodeterioration. A better understanding of how microorganisms are attracted to and attached to surfaces is needed.

Recently performed studies have uncovered facts that alter long held concepts of the sequence of events in the fouling process. ZoBell, at Scripps Institute of Oceanography, has demonstrated that adsorption of dissolved organic matter to surfaces exposed in sea water precedes the attachment of the bacteria. The bacteria utilize the adsorbed organic material as a source of nutrients and may be attracted by it.⁴¹ Preliminary results of studies underway at the Aerojet Corporation's Laboratory at Azusa, California reveal that pure cultures of marine bacteria do not readily adhere to surfaces exposed in sea water.⁴² When algae grow in the water, however, bacteria and other microorganisms are readily attached to the surfaces.

Microorganisms do not merely reside on the surfaces upon which they accumulate, but are securely fastened to the surfaces and can be removed only by drastic cleaning methods.⁴³ The composition of the cementing substance and the mechanism of adherence is not known.

That this substance is produced by algae or by the attaching microorganisms themselves is not known nor do we know that the substance is an attractant as well as an adhesive. Answers to these questions would likely provide clues for methods of preventing attachment of undesirable macro and microorganisms to surfaces of structures submerged in the ocean as well as surfaces of structures on land.

EXPERIMENTAL

Introduction

The study of biological corrosion was primarily confined to a "state of the art" search of the literature, but on a limited scale, laboratory experiments were also performed. One objective of the laboratory experiments was to determine relative rates of corrosion in a sterile environment and in an environment containing microorganisms. Another objective was to ascertain whether compounds of biochemical significance such as microbial metabolites, biological inhibitors, or biocidal agents influence corrosion rates. Because of their very great number, only a few such biochemicals were selected for laboratory investigation.

Methods and Materials

Measurement of Corrosion Rates. Corrosion rates were estimated by the simple procedure of determining the loss in weight of samples of iron after given exposures to a corrosive environment. The iron samples were weighed and then exposed to various corrosive environments for given periods of time. They were then freed of rust deposits, thoroughly cleaned, dried, and finally weighed again. The loss in weight was employed as a measure of the corrosion rate.

Iron Samples. Analytical grade iron wire in 70 millimeter lengths was wound into coils of about one millimeter diameter. The coils were formed around a large hypodermic needle into the end of which the wires were inserted and held fast while the coils were wound. Each iron sample consisted of three of the small coils of wire. The initial weights of the sets of three coils ranged from about 190 to about 220 milligrams and were recorded to the nearest tenth of a milligram.

Inoculum. No attempt was made to employ pure cultures of microorganisms, because mixed cultures of microorganisms involved in the corrosion of iron were desired. Scrapings and bits of soil surrounding a heavily corroded buried pipe and flakes of rust from a steel bar exposed in the harbor just above the water line, were mixed and

suspended in sea water containing glucose and beef extract. The resulting mixture was employed as the inoculum for the experiments performed in air. Scrapings from a block of wood removed from the harbor were added to the above described inoculum for the experiments in which influence of wood on the corrosion of metals was studied. Finally, scrapings from a submerged iron chain undergoing sulfide corrosion were added to the inoculum for the experiments performed under nitrogen or under a mixture of nitrogen and hydrogen sulfide. The latter inoculum was stored under a stream of nitrogen.

Gas Mixtures. Natural air was employed for the majority of the experiments. In those experiments requiring an oxygen-free atmosphere, water-pumped nitrogen gas was forced through the chambers in which the samples were stored. After the oxygen was flushed from the sample chamber, the flow of nitrogen was reduced to a rate of only a few milliliters per minute.

The mixtures of hydrogen sulfide and nitrogen employed for a few of the experiments were not of precise composition. A small hydrogen sulfide generator was placed in the nitrogen line. The generator contained numerous lumps of iron sulfide. A few milliliters of dilute hydrochloric acid were added daily (with the exception of weekends) and the hydrogen sulfide liberated was swept into the sample chamber by the incoming nitrogen. The flow of incoming nitrogen was sufficiently slow to preclude the sweeping away of all of the hydrogen sulfide in the sample chamber during a twenty-four-hour period.

The carbon dioxide-enriched air was produced in a similar manner. A carbon dioxide generator was inserted in the air line. The generator contained an excess of precipitated calcium carbonate and a few milliliters of dilute hydrochloric acid were added daily. Again, the flow of incoming air was sufficiently slow to preclude the sweeping away of all of the carbon dioxide from the sample chamber in a twenty-four-hour period. The carbon dioxide-free air was produced by slowly bubbling the air through a potassium hydroxide solution.

Removal of Rust. In several preliminary experiments, an ultrasonic cleaning bath was employed to remove rust from the iron samples. The cleaning process was facilitated with carborundum powder. The loss in weight of control samples which had not been exposed to corrosion but which were exposed to the cleaning process was barely detectable.

The ultrasonic cleaning method alone proved inadequate for cleaning many of the iron wires hence, the majority of the samples were cleaned by brief exposure to dilute hydrochloric acid to which an inhibitor or "pickling" agent was added. The samples were further cleaned in the ultrasonic cleaning bath. The loss in weight of control samples cleaned by the combined acid and ultrasonic method was measurable but did not exceed about one-half percent of the original weight of the samples.

Control of pH. Unless otherwise noted, the initial pH of the various solutions in which the iron wires were exposed was adjusted to within a half pH unit of neutrality. No adjustments in the pH of the solutions were made during the experiments, however, as the majority of the solutions were maintained in flasks closed with cotton plugs. The pH of some of the solutions changed considerably during the experiment and variable pH was no doubt one cause for variation in corrosion rates within different flasks and from experiment to experiment.

Sea Water. The sea water employed in the various experiments was drawn from a deep well driven near the shore of the ocean. Chemical analysis indicated that the ocean was the source of the well water. For some of the experiments a nutrient sea water was prepared by adding 1 gram of glucose and 0.5 gram of beef extract to one liter of sea water from the well.

General Procedure. The coils of iron wire in sets of three were placed in 50 milliliter Erlenmeyer flasks and covered with 20 milliliter portions of sea water or other aqueous mixtures. The flasks were then fitted with cotton plugs and sterilized in the autoclave under 15 pounds of pressure for one hour. (This treatment caused no detectible loss in weight of the iron wires.) When cool, the designated flasks were inoculated with a few drops of the appropriate mixture of nutrient sea water and natural rust deposits. The flasks were then stored in an incubator at 33°C for a stipulated period of time, usually three months. In the experiments in which gas mixtures other than air were utilized, the flasks were stored in large dessicator jars through which the gas mixture in question was forced to flow. The jars were partially immersed in a temperature-controlled water bath.

Experimental Results and Their Significance

The Influence of Oxygen on Corrosion. The iron wires corroded five to six times more rapidly in sterile sea water saturated with normal air than in sterile sea water saturated with oxygen-deficient air, i.e., with nitrogen (Table I). The true differences in aerobic

and anaerobic corrosion may be a little greater than indicated by Table I as there were several periods of several hours each at the beginning and end of the experiment when the anaerobic flasks were exposed to air. Furthermore, commercial nitrogen might contain traces of oxygen and small amounts of iron may have been removed with the rust when the samples were cleaned.

Table I. Influence of Mixed Wild Strains of Bacteria on the Corrosion of Iron Wire Immersed in Sea Water Containing No Added Nutrients

Percent Loss in Weight of Iron Wire in Three Months

Corrosion Environment	Bacteria Free	With Bacteria
Sea water saturated with air	10.1%	12.1%
Sea water saturated with air	12.5%	6.3%
Sea water saturated with nitrogen	1.7%	1.9%
Sea water saturated with nitrogen	2.0%	1.7%

The Influence of Bacteria on Corrosion. Bacteria had little or no influence on either the aerobic or anaerobic corrosion of iron wire immersed in sea water containing no added nutrients (Table I); but when they were supplied with a small amount of glucose and beef extract, bacteria had a great influence on anaerobic corrosion (Table II). In approximately three days the contents of the inoculated anaerobic flasks turned black and acquired the distinct odor of hydrogen sulfide. By the end of the experiment the combined loss in weight of the wires in the inoculated flasks was 6-1/2 times greater than the corresponding loss in weight of the wires in the sterile flasks.

Table II. Influence of Mixed Wild Strains of Bacteria on the Anaerobic Corrosion of Iron Wire Immersed in Nutrient Sea Water

Percent Loss in Weight of Iron Wire in Three Months

Corrosion Environment	Bacteria Free	With Bacteria
<u>Experiment A</u>		
Nutrient sea water saturated with nitrogen	1.2%	5.7%
Nutrient sea water saturated with nitrogen	1.7%	10.0%
<u>Experiment B</u>		
Nutrient sea water saturated with nitrogen	1.4%	11.0%
Nutrient sea water saturated with nitrogen	1.3%	10.2%

The Influence of Hyrdogen Sulfide on Corrosion. Bacteria were not essential for rapid corrosion in an anaerobic environment for their metabolic by-product, hydrogen sulfide, caused rapid and severe corrosion in an anaerobic environment in which no micro-organisms were present (Table III). When hydrogen sulfide-producing bacteria were also present, corrosion occurred at an even greater rate.

Table III. Influence of Hydrogen Sulfide on the Anaerobic Corrosion of Iron Wire Immersed in Nutrient Sea Water

Percent Loss in Weight of Iron Wire in Three Months

Corrosion Environment	Nitrogen Only*	Nitrogen and Hydrogen Sulfide
<u>Experiment A</u>		
Bacteria-free nutrient sea water	1.2%	24.0%
Bacteria-free nutrient sea water	1.7%	22.9%
<u>Experiment B</u>		
Bacteria-free nutrient sea water	1.4%	14.7%
Bacteria-free nutrient sea water	1.3%	14.8%
<u>Experiment A</u>		
Nutrient sea water inoculated with bacteria	5.7%	52.6%
Nutrient sea water inoculated with bacteria	10.0%	59.7%
<u>Experiment B</u>		
Nutrient sea water inoculated with bacteria	11.0%	31.5%
Nutrient sea water inoculated with bacteria	10.2%	35.6%

*Same data as Table II

The Influence of Wood on Corrosion. In tropical areas, corrugated steel buildings corrode rapidly, especially at spots where the sheets of corrugated steel come into contact with a wooden frame. Two experiments were performed to see if wood has either a direct influence on the corrosion of iron immersed in de-ionized water or in sea water containing no other organic material, or an indirect influence through its ability to support the growth of bacteria that accelerate corrosion (Tables IV and V). No experimental evidence was obtained to indicate that wood exerts such an influence on corrosion though the results do not rule out the possibility that wood-decaying fungi in a terrestrial environment might produce organic acids that accelerate corrosion rates.

Table IV. Influence of Mixed Strains of Microorganisms on the Corrosion of Iron Wire in Contact With Wood and Immersed in Air-Saturated Water

Corrosion Environment	Exposure Time (Months)	Loss in Weight (%)	
		Bacteria Free	Bacteria Present
Wire samples immersed in de-ionized water and covered with pine sawdust	2	9.2	5.2
	2	9.3	8.1
	4	16.5	17.1
	4	15.1	18.8
	4	17.8	22.0
Wire samples immersed in sea water and covered with pine sawdust	4	22.5	16.2
	2	11.9	11.6
	2	12.6	12.1
	4	21.5	28.6
	4	30.7	27.2
	4	24.9	23.8
	4	31.5	34.3

Table V. Influence of Wood on the Corrosion of Iron Wire Immersed in Sea Water

Percent Loss in Weight of Iron Wire in Three Months		
Corrosion Environment	No Sawdust* (%)	Sawdust Added (%)
<u>Saturated with Air (Aerobic)</u>		
Bacteria-free sea water	12.5 10.1	8.1 10.9
Sea water inoculated with bacteria	12.1 6.3	8.8 14.8
<u>Saturated with Nitrogen (Anaerobic)</u>		
Bacteria-free sea water	1.7 2.0	1.3 1.3
Sea water inoculated with bacteria	1.7 1.9	0.9 0.9

*Same data as Table I

Influence of Carbon Dioxide on Corrosion. Carbon dioxide is known to accelerate the corrosion of steel boilers and accordingly carbon dioxide as well as oxygen is commonly removed from feed water for boilers. The influence of carbon dioxide on corrosion is presumed to result from its effect on pH.

An experiment was performed to ascertain if carbon dioxide might participate in the corrosion process in a manner more fundamental than alteration pH (Table VI), but no evidence was obtained to indicate that such is the case. Corrosion rates in water aerated with carbon dioxide-deficient air were indistinguishable from corrosion rates in water aerated with normal air containing about 0.02 percent carbon dioxide. Only when carbon dioxide was present in concentrations sufficient to measurably influence pH, did it influence corrosion rates; and then its influence on corrosion was only slight.

Table VI. The Influence of Carbon Dioxide on the Corrosion of Iron Wire Immersed in Various Aqueous Solutions

Corrosion Environment	Initial pH	Final pH	Loss in Weight of Iron in Three Months (%)		
			CO ₂ -rich Air	Normal Air	CO ₂ -poor Air
De-ionized water	6.0	7.4-8.0	12.0	8.2	7.3
	6.0	7.4-8.0	10.8	10.3	10.4
Sea water	7.6	6.7-7.4	11.6	7.2	8.6
	7.6	6.7-7.4	10.9	7.9	7.5
Potassium-acid-phthalate buffer	4.3	5.7-5.8	43.3	39.5	43.2
	4.3	5.7-5.8	47.5	42.6	47.6

Influence of Biochemicals on Corrosion. Tables VII-XII present data concerning the influence of various compounds of biochemical significance, most of them organic compounds, on corrosion rates. In the experiments summarized in Tables VII and VIII, the water was autoclaved and no inoculum was added. Nevertheless, the flasks were not bacteria-free as aseptic techniques were not employed for adding the test compounds. For those experiments summarized in Tables IX and X, aseptic techniques were employed throughout. Of the compounds tested, only acetazolamide had a pronounced and reproducible influence on corrosion rates (Table XI).

Acetazolamide was not as effective an inhibitor of corrosion as was the well-known corrosion inhibitor, sodium dichromate, which was included for comparison (Table X). Acetazolamide was decidedly more effective than was 2-mercaptobenzothiazole, a corrosion inhibitor frequently used in brine lines in the oil fields. Acetazolamide did not, however, retard hydrogen sulfide corrosion though it slightly inhibited growth of hydrogen sulfide-producing bacteria (Table XII)

Ascorbic acid (Table IX) stopped all corrosion for the first two weeks of the experiment. No doubt it did this by virtue of its strong reducing properties. Ascorbic acid is, however, gradually oxidized by air and by the end of the experiment, corrosion proceeded rapidly in the flask to which ascorbic acid had been added.

Table VII. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in De-ionized Water

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Control (no additive)		16.1 22.0
Sodium sulfathiazole	A bacteriostatic agent - one of the sulfa drugs. An inhibitor of the enzyme, carbonic anhydrase.	16.4 14.7
Ferric chloride	An end-product of the corrosion of iron in chloride solutions. An analytical agent for dissolving iron.	21.7 19.1
Kojic acid	A fermentation product produced from carbohydrates by a variety of microorganisms.	23.2 20.7
Citric acid	A common intermediate of carbohydrate metabolism of plants, animals, and microorganisms.	10.6 11.5
Hemin	Iron-containing pigment of hemoglobin, the oxygen-carrying protein of red blood cells.	19.0 17.1
Glycerin	A common product of bacterial metabolism; also a break-down product of fats and oils.	18.2 20.4
Carbonic anhydrase	Respiratory enzyme catalyzing the reaction of carbon dioxide with water.	16.6 15.8

Table VIII. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in Sea Water

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Control (sea water only)		15.5
		16.9
Sodium sulfathiazole	A bacteriostatic agent of the sulfa drug class. A weak inhibitor of the enzyme, carbonic anhydrase.	17.3 18.0
Ferric chloride	An end-product of the corrosion of iron in chloride solutions. An analytical agent for dissolving iron.	19.0 20.7
Kojic acid	A fermentation product produced from carbohydrates by a variety of microorganisms.	16.4 15.1
Acetazolamide	A potent inhibitor of the respiratory enzyme, carbonic anhydrase.	3.4 1.3
Citric acid	A common intermediate of carbohydrate metabolism of plants, animals, and microorganisms.	12.9
		14.7
Hemin	Iron-containing pigment of hemoglobin, the oxygen-carrying protein of red blood cells.	15.1
		13.4
Glycerin	A common product of bacterial metabolism; also a break-down product of fats and oils.	15.1
		15.8
Carbonic anhydrase	Respiratory enzyme catalyzing the reaction of carbon dioxide with water.	15.7
		15.6

Table IX. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in Bacteria-free Sea Water

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Control (sea water only)		13.2
		17.1
Pentanedione (acetylacetonate)	An organic compound related structurally to two fermentation products. Complexes with iron salts.	24.1 20.5
Sodium sulfathiazole	A bacteriostatic agent, one of the sulfa drugs; and an inhibitor of the enzyme, carbonic anhydrase.	13.8
		12.1
Ferric chloride	An end product of the corrosion of iron in chloride solutions. An analytical agent for dissolving iron.	18.4
		18.8
Kojic acid	A fermentation product produced from carbohydrates by a variety of microorganisms.	14.4
		14.8
Acetazolamide	A potent inhibitor of the respiratory enzyme, carbonic anhydrase.	3.4
		2.1
Citric acid	A common intermediate of carbohydrate metabolism of plants, animals, and microorganisms.	19.6
		18.9
Hemin	Iron-containing pigment of hemoglobin, the oxygen-carrying protein of red blood cells.	14.9
		15.9
Glycerin	A common product of bacterial metabolism; also a breakdown product of fats and oils.	15.7
		17.6
Oxalic acid	A fermentation product. Is released during decomposition of wood. Complexes with iron salts.	22.0
		19.2

Table X. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in Bacteria-free Sea Water

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Control (sea water only)		15.2 14.1
Acetylmethylcarbinol (or acetoin)	Fermentation product with bread-like odor. Its production by bacteria is used as basis for classification.	17.5 16.3
Citric acid	A common intermediate of carbohydrate metabolism of plants, animals, and microorganisms.	7.9 9.2
Tartaric acid	Fermentation product produced in wine making. Used to flavor soft drinks. Rotates polarized light.	7.8 6.9
Indole	Produced by colon bacteria. Has distinct feces-like odor.	12.7 15.6
Benzoic acid	Produced by fruits and berries. is used as food preservative and as a rust inhibitor.	14.0 14.7
Ascorbic acid (or Vitamin C)	Used as a food supplement and as an anti-oxidant to prevent rancidity of fats and browning of apples.	9.3 9.4
Riboflavin (or Vitamin B ₂)	Yellow pigment produced by microorganisms and used by all animals. Participates in enzymic oxidations.	11.5 10.8
Thiamine (or Vitamin B ₁)	Distributed widely in nature. Produced by yeasts. Participates in enzymic carboxylation reactions.	11.5 14.8

Continued

Table X. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in Bacteria-free Sea Water (Contd)

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Sodium cyanide	Violent poison. A reducing agent which immobilizes hemoglobin. Complexes with iron compounds.	13.5 13.0
Sodium azide	A specific enzyme inhibitor. Blocks enzymatic oxidation and reduction but has no effect on glycolysis.	12.1 12.3
Sodium dichromate	A powerful oxidizing agent that inhibits the corrosion of iron immersed in sea water.	0.0 1.0
Allantoin	Birds excrete most of their protein nitrogen as uric acid which is oxidized to allantoin by bacteria.	18.1 16.3
2-Propylthioracil	An anti-thyroid agent.	15.9 15.4
Sulfaguanidine	A bacteriostatic agent - one of the sulfa drugs. Is an inhibitor of the enzyme carbonic anhydrase.	12.1 11.9
Sulfanilamide	A bacteriostatic agent - one of the sulfa drugs. Is an inhibitor of the enzyme carbonic anhydrase.	12.6 11.1
Cupferon	An organic compound that forms stable complexes with various iron salts.	23.2 22.4
Sodium barbital	A sedative with a long duration of action. Effects respiratory rate.	17.1 15.3

Continued

Table X. The Influence of Numerous Compounds of Biochemical Significance on the Aerobic Corrosion of Iron Wire Immersed in Bacteria-free Sea Water (Contd)

Compound (All at conc. of 0.1 gms/100 ml.)	Description of Compound	Loss in Weight of Iron Wire in Three Months (%)
Acetazolamide	A potent inhibitor of the respiratory enzyme carbonic anhydrase	2.2
		2.4
2-Mercaptobenzo- thiazole	A rust inhibitor commonly used in the oil fields. Is also bacteriacidal to some organisms.	13.8 10.0
Kojic acid	Fermentation product produced from carbohydrates by a variety of micro-organisms. Reacts with iron salts.	11.0
		10.3
Commercial "pickling" agent	A mixture of compounds used to prevent the reaction of acid with iron during cleaning.	18.1
		14.9

Table XI. Review of the Inhibiting Effect of Acetazolamide on Aerobic Corrosion in Sea Water

Corrosion Environment	Loss in Weight of Iron Wire in Three Months (%)*	
	Without Acetazolamide	With Acetazolamide (0.1 gms/ml)
<u>Experiment A</u> Wire immersed in sea water	15.5	4.4
	16.9	1.9
<u>Experiment B</u> Wire immersed in bacteria-free sea water	13.0	3.4
	17.1	1.7
<u>Experiment C</u> Wire immersed in bacteria-free sea water	15.1	1.1
	14.1	1.4

*Same data as on Tables VIII, IX, and X.

Table XII. Influence of Acetazolamide on Anaerobic Sulfide Corrosion

Corrosion Environment	Loss in Weight of Iron Wire in Three Months (%)	
	Without Acetazolamide*	With Acetazolamide (0.1 gm/100 ml.)
<u>Aerated with Nitrogen Only (oxygen free)</u>		
Bacteria-free nutrient sea water	1.4	1.4
	1.3	1.5
Bacteria-inoculated nutrient sea water	11.0	1.4
	10.2	7.6
<u>Aerated with Mixture of Nitrogen and Hydrogen Sulfide (oxygen free)</u>		
Bacteria-free nutrient sea water	14.7	15.6
	14.3	15.3
Bacteria-inoculated nutrient sea water	31.5	21.5
	35.6	26.3

*Same data as on Table III

FINDINGS

Findings of Survey of Corrosion Problems at Naval Shore Facilities.

1. The corrosion of buried tanks and pipelines is no longer as serious a problem at Naval activities as it was formerly. The problem is being solved by the construction of better drainage trenches, by the application of cathodic protection, and by the use of plastic pipelines.
2. Methods of preventing the corrosion of above ground metal structures are not as effective as is desired, but corrosion of such structures at Naval activities is a relatively minor problem.
3. The corrosion of major waterfront structures is the most serious problem associated with the deterioration of iron and steel structures at Naval activities. Corrosion of steel waterfront structures is most severe in the regions wetted periodically by sea water.

Findings of Review of Literature on Organisms that Influence Corrosion

1. Specific microorganisms can significantly accelerate corrosion by producing acids or by producing hydrogen sulfide, both of which are extremely corrosive to iron, steel, and certain other metals.
2. Accumulation of non-specific microorganisms and larger fouling organisms can foster the establishment of regions of differential oxygen concentrations on a metal surface. This condition leads to localized corrosion and pitting of the metal at the regions of lowest oxygen concentration.
3. Microorganisms can reduce the general concentration of oxygen in the neighborhood of a metal surface or object and thereby retard its corrosion.

Findings of Experiments Performed at NCEL

1. In bacteria-free sea water, iron corrodes at least five times more rapidly in the presence than in the absence of oxygen.
2. When exposed to air, iron corrodes just as rapidly in bacteria-free sea water as in sea water containing numerous wild strains of fouling microorganisms.

3. Iron submerged in sea water from which oxygen is excluded rusts very slowly unless sulfate-reducing bacteria or their metabolic by-product, hydrogen sulfide, are present. To induce rapid anaerobic corrosion, the bacteria must be supplied with carbohydrates or other nutrients.

4. Most organic compounds appear to have but little, if any, influence on the corrosion of iron immersed in sea water unless the compounds are oxidizing or reducing agents or unless they significantly change the pH of the sea water.

5. The carbonic anhydrase inhibitor, acetazolamide, however, is an effective inhibitor of sea water corrosion and might be useful as an agent for imparting corrosion resistance to protective coatings and concrete.

CONCLUSIONS

Microorganisms frequently play a significant role in the corrosion of buried pipes and tanks, a problem which at Naval activities is frequently severe below the water line. Underground corrosion can all but be eliminated, however, by the application of cathodic protection, by the use of substitute materials, and by the construction of better drainage trenches. Bacterial processes probably do not significantly alter the aerobic corrosion of structures above ground, in any event a relatively minor problem at Naval activities.

Bacterial processes undoubtedly have a marked influence on the corrosion of structures wholly submerged in the ocean. In most instances the bacteria probably retard corrosion by reducing the concentration of oxygen, but in some instances bacterial processes promote very severe and rapid corrosion of iron submerged in the ocean.

Bacteria are of dubious significance in promoting corrosion in the splash zone, the area of most concern to the Navy. Sulfur-oxidizing bacteria and unicellular photosynthetic algae might accelerate splash zone corrosion, but even if economical methods were available to stop the growth of microorganisms on metal surfaces, splash zone corrosion would still proceed quite rapidly.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory (NCEL). Technical Note N-819: Survey of bioscience problems at BUDOCKS activities, by H. P. Vind and T. B. O'Neill. Port Hueneme, California, 1 November 1965.
2. NCEL. Technical Note N-700: A survey of pipe corrosion at naval activities, by J. M. Stephenson. Port Hueneme, California, 26 March 1965.
3. NCEL. Technical Note N-506: Plastic pipe in-service test (12ND), 2nd report, by R. J. Zablodil. Port Hueneme, California, 17 May 1963.
4. NCEL. Technical Report R-225: Corrosion-resistant nonmetallic materials for pipe and pipe jackets or linings - a literature survey, by T. Roe, Jr., and R. L. Alumbaugh. Port Hueneme, Calif., 2 January 1963.
5. American Gas Association. Final report of the American Gas Association Iron Corrosion Research Fellowship: Anaerobic corrosion of iron in soil, by R. L. Starkey and K. M. Wight. New York, 1945.
6. NCEL. Technical Report R-097: Corrosion survey of steel sheet piling, by C. V. Brouillette and A. E. Hanna. Port Hueneme, Calif., 27 December 1960.
7. King and Gavaris, Consulting Engineers. Contract NBy-50996 (A&E): Restudy existing sheet pile bulkhead, Naval Air Station, Floyd Bennett Field, New York, 6 November 1963.
8. David M. Updegraff. "Microbiological corrosion of iron and steel," Corrosion, vol. 11, no. 10, Oct. 1955, pp. 442t-446t.
9. R. L. Starkey. "The general physiology of the sulfate-reducing bacteria in relation to corrosion," Producers Monthly, vol. 22, no. 8, June 1958, pp. 12-30.
10. C. E. ZoBell. "Ecology of sulfate-reducing bacteria," Producers Monthly, vol. 22, no. 7, May 1958, pp. 12-29.
11. W. Summer. "Microbially induced corrosion," Corrosion Technol. vol. 7, September 1960, pp. 287-288.
12. M. P. Silverman and D. G. Lundgren. "The chemo-autotrophic iron bacterium, Ferrobacillus ferrooxidans," I-J. Bacteriology, vol. 77, 1959, pp. 642-7; II-J. Bacteriology, vol. 78, 1959, pp. 326-331.

13. O. N. Al'bitskaya and N. A. Shaposhnikova. "The effect of molds on the corrosion of metals," *Microbiology*, vol. 29, March to April 1961, pp. 524-527.
14. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Report ASD-TDR-63-752, prepared under contract AF 33(657)-10865: Elementary hydrocarbon microbiology, by Sharpley Laboratories, Inc., Fredericksburg, Va., April 1964 (295 pages).
15. J. J. Bunkie and K. R. Butlin. "The culture and activities of sulfate-reducing bacteria," Report on the Proceedings of 4th International Congress of Microbiology. 1947, pp. 457-459.
16. I. B. Ulanovskii, N. I. Tarasov, and Yu. M. Korovin. "The effect of sea-acorns on the corrosion of stainless steels," *Doklady Akad. Nauk S. S. S. R.*, vol. 125, 1959, pp. 1137-1140.
17. NCEL. Technical Note N-767: Protective coatings in shallow and deep ocean environments, by C. V. Brouillette, R. W. Drisko, and R. L. Alumbaugh. Port Hueneme, California, 20 August 1965.
18. Margaret Irwin. "Steel-boring sea urchins," *Pacific Discovery*, vol. 6, no. 2, March-April 1953, pp. 26, 27.
19. NCEL. Technical Report R-132: The effects of marine organisms on engineering materials for deep-ocean use, by J. S. Muraoka. Port Hueneme, California, March 1962.
20. T. M. Skerman. "The nature and development of primary films on surfaces submerged in the sea," *New Zealand Journal of Science and Technology*, vol. 38, B, July 1956, pp. 44-57.
21. C. E. ZoBell. "The effect of solid surfaces upon bacterial activity," *J. Bacteriology*, vol. 46, 1943, pp. 39-56.
22. Byron J. Mechals, Research Microbiologist, Aerojet-General Corporation, Azusa, California. Private communications.

Appendix A

BIBLIOGRAPHY ON BIOLOGICAL CORROSION

EXPLANATORY REMARKS

This bibliography includes many articles that do not pertain directly to biological corrosion. For example, a number of the listed articles pertain only to the physiology and distribution of sulfate-reducing bacteria, iron bacteria, or marine fouling organisms. Even though such articles may contain no reference to the corrosion of metals, they may be of considerable interest to one studying biological corrosion, and therefore they have been included in this bibliography. Similarly, a number of articles listed in the bibliography pertain more specifically to the deterioration of hydrocarbon fuels than to corrosion. A few such articles have been included because of the frequent association of the deterioration of metal fuel tanks and the deterioration of hydrocarbon fuels. Although the Bibliography on Biological Corrosion does not include abstracts of the referenced articles, in most cases it gives the location of readily available abstracts.

Location of Chemical Abstracts references are given by volume, column, and line; e. g., CA 44:1167g, refers to Chemical Abstracts, Volume 44, Column 1167, Line g. The Chemical Abstracts are among the best known and readily available abstracts of scientific articles. Chemical Abstracts coverage of journals devoted to theoretical and fundamental studies is especially good, but its coverage of journals and technical magazines devoted to applied science and its coverage of government reports is incomplete.

The National Association of Corrosion Engineers (NACE) has for many years prepared abstracts from the technical literature of articles pertaining to corrosion. Their coverage of government reports and applied technical articles is especially good. Prior to 1962 the NACE Abstracts were printed on numbered punched cards which could be readily key-sorted into numerous sub-topics. Although NACE Cards are available in only a restricted number of libraries, the NACE Card numbers are given in the NCEL Bibliography on Biological Corrosion.

In 1962, NACE discontinued its printing of abstracts on punched cards and commenced publication of Corrosion Abstracts, a periodical. References to Corrosion Abstracts are given by volume, date, and page.

In 1963 the Prevention of Deterioration Center (PDC) of the National Research Council prepared a Bibliography on Microbial Corrosion of Metals. The bibliography is readily available. It includes abstracts of articles on microbial corrosion, but it contains no index. References to the Prevention of Deterioration Center's Bibliography on Microbial Corrosion of Metals are abbreviated PDC Bi followed by the special number, usually a PDL-number, assigned to the article by the Prevention of Deterioration Center, and by the page number. A few articles abstracted by the Prevention of Deterioration Center and assigned a PDL-number were not included in their Bibliography on Microbial Corrosion of Metals. These are merely referred to by PDL-number.

1. Adams, M. E., K. R. Butlin, S. J. Hollands, and J. R. Postgate. "Role of hydrogenase in the autotrophy of Desulfovibrio," RESEARCH (London) 4, (1951) pp. 245-6. Abstr. in CA 46:4056f.
2. Adams, M. E., and T. W. Farrar. "The influence of ferrous iron on bacterial corrosion," J. APPLIED CHEM., 3, Part 3, (1953) pp. 117-120. Abstr. on NACE card 6291 in CA 47:11343b, and in PDC Bi G-8889, p. 27.
3. Adams, M. E., and J. R. Postgate. "Sporulation in sulfate-reducing bacteria," J. GEN. MICROBIOL., 24, (1961) pp. 291-4. Abstr. in CA 55:18875h.
4. Adams, M. E., and J. R. Postgate. "A new sulfate-reducing vibrio," J. GEN. MICROBIOL., 20, (1959) pp. 252-7. Abstr. in CA 53:15204f.
5. Akagi, J. M., and L. L. Campbell. "Studies on thermophilic sulfate-reducing bacteria. II. Hydrogenase activity of Clostridium nigrificans." J. BACTERIOL., 82, (1961) pp. 927-32. Abstr. in PDC Bi PDL-43034, p. 60.
6. Akagi, J. M., and L. L. Campbell. "Thermophilic sulfate-reducing bacteria. III. Andenosine triphosphate-sulfurylase of Clostridium nigrificans and Desulfovibrio desulfuricans." J. BACTERIOL., 84, (1962). Abstr. in CA 58:5933.
7. Al'bitskaya, O. N., and N. A. Shaposhnikova. "The effect of molds on the corrosion of metals," MICROBIOLOGY, 29, (Mar.-April 1961) pp. 524-27. Abstr. in PDC Bi PDL-41984, p. 57.
8. Alexander, A. L., B. W. Forgeson, H. W. Mundt, C. R. Southwell, and L. J. Thompson. "Corrosion of metals in tropical environments. Part I. Test methods used and results obtained for pure metals and a structural steel." U. S. Naval Research Laboratory. Report 4929: ASTIA DOC. 153210 (June 1957) 44 pp. Abstr. in PDC Bi PDL-30540, p. 40.

9. Allred, R. C. "The role of micro-organisms in oil field water flooding operations; bacterial control on north Burbank unit water flood, Osage County, Okla." PRODUCER'S MONTHLY, 18:(4) (Feb. 1954) pp. 18-22. Abstr. in CA 48:9094f and in PDC Bi G-10350, p. 31.
10. Allred, R. C., T. A. Mills, and H. B. Fisher. "Bacteriological techniques applicable to the control of sulfate-reducing bacteria in water flooding operations." PRODUCER'S MONTHLY, 19:(2) (Dec. 1954) pp. 31-32. Abstr. in CA 49:4212b and in PDC Bi PDL-42812, p. 59.
11. American Petroleum Institute, Pacific Coast District Study Committee on Treatment and Control of Injection Waters. Proceedings, "Second biennial symposium on microbiology." (1964).
12. American Society of Mechanical Engineers. "Symposium on marine fouling." TRANS. ASME, 72, No. 2 (Feb. 1950), pp. 101-131. Abstr. in CA 44:3665c.
13. Amstutz, R. W. "Corrosion problems in water flooding." CORROSION, 14 (1958), pp. 255t-259t. Abstr. in CA 52:9924c.
14. Anonymous. "The bacterial corrosion of iron and concrete." MINING J. (London), 234 (May 1950), pp. 450-451. Abstr. in PDC Bi G-7472, p. 20.
15. Anonymous. "Effect of bacteria on non-ferrous metals needs investigation, group says." CORROSION, 12 (July 1956), p. 86. Abstr. in PDC Bi G-12847, p. 37.
16. Anonymous. "Corroding pipes and bacteria." DISCOVERY, 8 (April 1947), p. 102. Abstr. in PDC Bi G-1338, p. 11.
17. Anonymous. "Underground corrosion of pipelines." TIMES REV. IND., 4:(41), (June 1950), pp. 20-22. Abstr. in PDC Bi G-6332, p. 20.
18. Anonymous. "Corrosion of buried pipes; sulphate-reducing bacteria." WATER AND WATER ENG., 50 (April 1947), pp. 203-204. Abstr. in PDC Bi G-6216, p. 19.
19. Arbuzova, K. S., and V. V. Patrikeev. "The role of Balanus in the corrosion of stainless steel in the Black Sea." NAUK S.S.S.R., 132 (May 1960), pp. 693-695. Abstr. on NACE card 22250A.
20. Arnaudi, C., and G. Banfi. "Zinc alterations and activity of sulfate-reducing bacteria in dilute salt solutions." ANN. MICROBIOL., 6 (1954), pp. 18-40. Abstr. in CA 49:4791g.

21. Arnaudi, C. "Action of germs in metal corrosion." ANN. MICROBIOL., 5 (1952), pp. 26-40. Abstr. in CA 47:831f.
22. Azaroff, N. L. "Sulfate requirement for iron oxidation by Thiobacillus ferrooxidans." J. BACTERIOL., 85 (1963), pp. 78-83. Abstr. in CA 58:4829a.
23. Baas-Becking, L. G. M., "Biological processes in the estaurine environment. I., II., Ecology of the sulfur cycle." KONINKL NED. AKAD. WETENSCHAP, Proc. 58B (1955), pp. 160-172, 173-181. (in English) Abstr. in CA 50:7210b.
24. Baas-Becking, L. G. M., and I. R. Kaplan. "Biol. processes in the estaurine environment. III. Electrochemical considerations regarding the sulfur cycle. IV. Interpretation of observed E_p -pH relations of various members of the sulfur cycle." KONINKL NED. AKAD. WETENSCHAP, Proc. Ser. B, 59 (1956), pp. 85-96, 97-108. (in English) Abstr. in CA 50:16983e.
25. Baas-Becking, L. G. M., and M. Mackay. IBID. 109-117, 118-123, "Influence of enteromorpha upon its environment."
26. Baas-Becking, L. G. M., E. J. Ferguson, and I. R. Kaplan. "Biol. processes in the estaurine environment. VIII. Iron bacteria are gradient organisms." KONINKL NED. AKAD. WETENSCHAP Proc. Ser. B, 59 (1956), pp. 398-407. Abstr. in CA 51:6917a.
27. Baba, T., and T. Yoshino. "Corrosion inhibiting effect of Imidazoline compounds." J. CHEM. SOC. (Japan) Ind. Chem. Sect., 64, No. 5 (May 1961) pp. 902-909. Abstr. in Corrosion Abstracts.
28. Bachemheimer, A. G., and E. O. Bennett. "Sensitivity of mixed populations of bacteria to inhibitors. I. Mechanism by which D. desulfuricans protects Pseudomonas aeruginosa from the toxicity of mercurials." J. MICROBIOL. SEROL., 27 (1961), pp. 180-188. Abstr. in CA 55:26103h.
29. Bahr, H., and W. Schwartz. "Investigations on the ecology of colorless, thready sulfur microbes." BIOL. ZENTR., 75 (1950), pp. 451-464. Abstr. in PDC Bi PDL-32893, p. 42.
30. Baliga, B. S., H. G. Vartak, and V. Jagannathan. "Purification and properties of sulfurylase from D. desulfuricans." J. SCI. IND. RESEARCH (India) (1961), 20c, pp. 33-40. Abstr. in CA 55:17765f.
31. Banfi, Guido. "Relation between Zn alteration and the activity of sulfate-reducing bacteria in diluted salt solutions." III. ANN. MICROBIOL., 7 (1956), pp. 111-31. Abstr. in CA 51:16719f.

32. Banfi, G. "Microbes and metallic corrosion." CHIMICA E INDUSTRIA (Milan), 34 (1952), pp. 17-21. Abstr. in CA 46:5509h.
33. Barghoorn, E. S., and R. L. Nichols. "Sulfate-reducing bacteria and pyritic sediments in Antarctica." SCIENCE, 134 (July 1961), p. 190.
34. Baudon, Lucien. "The role of micro-organisms in certain corrosion phenomena." IND. CHEM. BELGE., Vol. 23 (Sept. 1958), pp. 983-990. Abstr. on NACE card 17175 and in PDC Bi PDL-38623, p. 51.
35. Baughman, J. L. "Marine fouling and boring organisms." Paper before NACE, Houston, Sept. 9, 1947. Publ. in CORROSION, 5, No. 4 (1949), pp. 113-119. Abstr. in NACE Bibliography.
36. Baumgartner, A. W. "Sulfate-reducing bacteria - their role in corrosion and well-plugging." PRODUCER'S MONTHLY, 26, No. 7 (1962), pp. 2-5. Abstr. in CA-58:760g and in PDC Bi PDL-47001, p. 69.
37. Baumgartner, A. W. "Microbiological corrosion - What causes it and how it can be controlled." J. PETROL. TECHNOL., 14 (1962). Abstr. in CA 58:3253g.
38. Beck, J. V. "A ferrous-ion-oxidizing bacterium. I. Isolation and some general physiological characteristics." J. BACTERIOL., 79 (1960), pp. 502-509. Abstr. in CA 54:15523h and in PDC Bi PDL-36934, p. 46.
39. Beckwith, T. D. "Corrosion of iron by biological oxidation of sulfur and sulfides." PREVEN. DETERIORATION ABST., 4, No. 2 (1947). Abstr. in PDC Bi G-775, p. 9.
40. Beecher, J. S., and G. A. Trautenberg. "Control biological growths in open-circulating cooling-water systems." POWER, 103, No. 4 (April 1964), pp. 80-82. Abstr. in Corrosion Abstr. 4 (Jan. 1965), p. 14.
41. Bennett, E. O., G. J. Guynes, and D. L. Isenberg. "The sensitivity of sulfate-reducing bacteria to antibacterial agents. II. Phenolic compounds." PRODUCER'S MONTHLY, 23:(1) (Nov. 1954), pp. 18-19. Abstr. in PDC Bi PDL-43049, p. 61.
42. Bennett, E. O., G. J. Guynes, and D. L. Isenberg. "The sensitivity of sulfate-reducing bacteria to antibacterial agents. III. The nitro-paraffin derivatives." PRODUCER'S MONTHLY, 24, No. 5 (1960), pp. 26-27. Abstr. in CA 54:18660c and in PDC Bi PDL-43050, p. 61.

43. Bennett, E. O., and E. B. Hodge. "Control of sulfate-reducing bacteria during recovery of oil by water-flooding." US Pat. 3,001,934. Appl. April 2, 1959; US Pat. 3,001, 935-6. Appl. May 13, 1959. Abstr. in CA 56:2649h.
44. Bennett, E. O., and E. B. Hodge. "Control of bacteria in water-flooding operations." US Pat. No. 2,976,236. March 21, 1961. Abstr. in CA 55:19220.
45. Berger, U., and E. Einstmann. "Oligodynamic action of a few new structural metals." (includes English summary) ARCH. HYG. U. BAKTERIOL., 143 (Dec. 1959), pp. 634-640. Abstr. in PDC Bi PDL-37722, p. 49.
46. Bernard, G. G. "Control of bacteria in oil-well flooding waters." US Pat No. 2,912,378. Nov. 10, 1959. Abstr. in CA 54:3931i.
47. Birkholz, D. O., M. R. Rogers, and A. M. Kaplan. "The microbiological deterioration of hydrocarbons and the related degradation of equipment used for the storage, distribution and handling of petroleum products." A selected bibliography. MICROBIOLOGICAL DETERIORATION SERIES NO. 5, Supplement No. 1 (March 1962), 16 pp. Abstr. in PDC Bi PDL-43823, p. 63.
48. Birkholz, D. O., M. R. Rogers, and A. M. Kaplan. "The microbiological deterioration of hydrocarbons and the related degradation of equipment used for the storage, distribution, and handling of petroleum products." A selected bibliography. MICROBIOLOGICAL DETERIORATION SERIES NO. 5 (June 1961), 19 pp. Abstr. in PDC Bi PDL-41206, p. 54.
49. Bombara, G., D. Cherardi, and E. Zannini. "Electro-chemistry of sulfate-reducing bacteria." RICERCA SCI., 29 (1959), pp. 484-495. Abstr. in CA 54:11041i.
50. Booth, G. H. "A study of the effect of tannins on the growth of sulphate-reducing bacteria." J. APPLIED BACTERIA, 23 (1960), pp. 175-179. Abstr. in PDC Bi PDL-41704, p. 56.
51. Booth, G. H. "Sulphur bacteria in relation to corrosion." J. APPL. BACTERIOL. 27, No. 1 (April 1964), pp. 174-181. Abstr. in Corrosion Abstr. 4 (March 1965), p. 99.
52. Booth, G. H., and A. K. Tiller. "Polarization studies of mild steel in cultures of sulfate-reducing bacteria. III. Halophilic organisms." TRANS. FARADAY SOC. 58 (1962), pp. 1517-1519. Abstr. in CA 56:333d and in PDC Bi PDL-40809, p. 144.

53. Booth, G. H., A. K. Tiller, and F. Wormwell. "A laboratory study of well-preserved ancient iron nails from apparently corrosive soils." *CORROSION SCI.* 2 (1962), pp. 197-202.
54. Bradley, W. G. "A study of galvanic corrosion in marine pseudo-sediments." Tech. Report, Texas A&M Project No. 24-A (September 1954), 73 pp., ASTIA DOC. 45679. Abstr. on NACE card 10659 and in PDC Bi G-11031, p. 33.
55. Bridgeport Brass Co., Bridgeport, Conn. "New brass resists algae growth." *MATERIALS IN DESIGN ENG.* 52:(1), (July 1960), p. 10. Abstr. in PDC Bi PDL-37242, p. 46.
56. British non-Ferrous Metals Research Assoc. "Select Bibliography on fouling in marine water circuits." (Oct. 1943), (B.N.F. Serial No. 36,595) 1952, 2 pp., *BULL. BRIT. NON-FERROUS METALS ASSOC.* 33, No. 283,16 (1953). Abstr. on NACE card 8326.
57. Brouillette, C. V. "Corrosion rates in Port Hueneme harbor." *CORROSION* 14 (August 1958), No. 8, pp. 352t-356t.
58. Brouillette, C. V., R. W. Drisko, and R. L. Alumbaugh. "Protective coatings in shallow and deep ocean environments." U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-767 (Aug. 1965).
59. Brouillette, C. V. and A. E. Hanna. "Corrosion survey of sheet piling." U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, Technical Report R-097 (27 Dec. 1960).
60. Bryner, L. C., J. V. Beck, D. B. Davis, D. G. Wilson. "Microorganisms in leaching sulfide minerals." *IND. ENG. CHEM.* 46 (December 1954), pp. 2587-2593. Abstr. in PDC Bi G-10610, p. 32.
61. Buck, J. D., and R. C. Cleverdon. "H₂S produced by some agarolytic marine bacteria." *CAN. J. MICROBIOL.* 5 (Oct. 1960), pp. 594-595. Abstr. in PDL-39166, vol. 18 (1960).
62. Buckman, S., J. D. Fera, and J. W. Appling. "Processes for the control of iron bacteria and compositions for use therein." US Pat No. 2,919,758. March 20, 1960, 5 p. Abstr. in PDC Bi PDL-38245, p. 50.
63. Bunker, H. J. "Micro-biological experiments in anaerobic corrosion." *SOC. CHEM. IND. (London)* 1. 25, pp. 91-100. Abstr. in PDC Bi X-013, p. 38.

64. Bunkie, H. J., and K. R. Butlin. "The culture and activities of sulfate-reducing bacteria." Report on the Proceedings of 4th International Congress of Microbiology. (1947), pp. 457-459. Abstr. in CA 44:1167g.
65. Butlin, K. R., "Bacteria which destroy steel." DISCOVERY 9 (1948), pp. 151-4. Abstr. in Chem. Abstr. 42:5400f.
66. Butlin, K. R. "Some malodorous activities of sulphate-reducing bacteria." SOC. APPL. BACTERIOL. PROC. 12, (2) (1949), pp. 39-42. Abstr. in PDC Bi PDL-30848, p. 41.
67. Butlin, K. R. "The bacterial sulfur cycle." RESEARCH 6, No. 5 (May 1953), pp. 184-191. Abstr. on NACE card 6253.
68. Butlin, K. R. "General micro-biological processes - autotroph. micro-organisms." Reports on the progress of Appld. Chem. SOC. OF CHEM. IND., LONDON 39 (1954), 1125 pp. Abstr. in CA 50:510d.
69. Butlin, K. R., and M. E. Adams. "Autotrophic growth of sulfate-reducing bacteria." NATURE 160 (1947), pp. 154-5. Abstr. in CA 41:6921j.
70. Butlin, K. R., M. E. Adams, and M. Thomas. "Sulphate-reducing bacteria and internal corrosion of ferrous pipes conveying water." NATURE 163 (Jan. 1949), pp. 26-27. Abstr. in PDC Bi G-3506, p. 17.
71. Butlin, K. R., M. E. Adams, and M. Thomas. "Isolation and cultivation of sulfate-reducing bacteria." J. GEN. MICROBIOL. 3 (1949), pp. 46-59. Abstr. in CA 43:4328g.
72. Butlin, K. R., and J. R. Postgate. "The economic imp. of autotrophic microorganisms." Ibid. pp. 271-304. Abstr. in CA 43:8863d.
73. Butlin, K. R., and W. H. J. Vernon. "Investigations on underground corrosion." British Iron and Steel Research Association, London, Metallurgy Division. Sub-committee on the corrosion of buried metals. Paper MG/BE/34/51 (Dec. 1951), 10 pp. Abstr. in PDC Bi G-8150, p. 22.
74. Butlin, K. R., W. H. J. Vernon, and L. F. Whiskin. "Underground corrosion." WATER AND SANITARY ENGINEERING 2 (1952), pp. 468-72. Abstr. in CA 48:1927c.

75. Butlin, K. R., W. H. J. Vernon, and L. P. Whiskin. "Investigations of underground corrosion." WATER AND WATER ENG. 56, No. 671 (Jan. 1952), pp. 15-18.
76. Caldwell, J. A., and M. L. Lytle. "Corrosion inhibitor for oil wells containing hydrogen sulfide." US Pat. No. 2,614,982. October 21, 1952. Abstr. in CA 47:1922h.
77. Caldwell, J. A., and Melba L. Lytle. "Preventing corrosion of oil well casings by sulfate-reducing bacteria." US Pat. No. 2,906,708 (Sept. 29, 1959). Abstr. in CA 54:2733d and in PDC B1 PDL-35845, p. 45.
78. Caldwell, J. A. and M. L. Lytle. "Bacterial corrosion of offshore structures." CORROSION 9, No. 6 (June 1953), pp. 192-196. Abstr. in PDC B1 G-9195, p. 29.
79. Callame, Bernard. "Biological factors influencing sea water corrosion." CORROSION ET ANTICORROSION 7 (May 1959), pp. 173-177. Abstr. on NACE card 18346.
80. Callame, B. "Organisms responsible for fouling ship's hulls." CORROSION TECHNOLOGY 2 (Sept. 1955), pp. 294-295. Abstr. on NACE card 12688.
81. Carlson, V. E. O. Bennett, and J. A. Rowe, Jr. "Microbial flora in a number of oilfield water-injection systems." SOC. PETROL. ENGRS. J. 1 (June 1961), pp. 71-80. Abstr. in PDC B1 PDL-43525, p. 63
82. Chistyakov, V. M., and M. I. Kononova. "Benzoic acid as a corrosion inhibitor for carbon steel in moist acidic carbon tetrachloride." (in Russian) IZVEST. VYSSHIKH. UCHEB. ZAVEDENY NEFT'I GAZ, No. 11 (1961), pp. 103-105. Abstr. in Corrosion Abstracts.
83. Churchhill, A. V., "Microbial fuel tank corrosion: mechanisms and contributory factors." MATERIALS PROTECTION 2, 18-20 (June 1963), pp. 22-23. Abstr. in PDC B1 PDL-48219, p. 69.
84. Clapp, W. "Penetration of protective coatings by marine organisms." 3rd Symp. on Varn. & Paint Chem., New York Univ., College of Eng., (1950), pp. 41-42. Abstr. on NACE card 5892.

85. Claus, D., H. Wittman, and A. Rippel-Baldes. "Studies on the composition of bacterial slimes and their ability to dissolve difficultly soluble inorganic compounds." (in German) ARCH. MICROBIOL. 29 (Feb. 1958), pp. 169-178. Abstr. in PDL 34186. Vol. 17, 1959, Biol. 3.
86. Clifton, C. E. "Annual review of microbiology." Vol. 5, Stanford, Calif., Annual Reviews Inc. (1951), 379 pp. Abstr. in PDC Bi R-293, p. 38.
87. Colegate, G. T. "The corrosion of marine structures and its prevention." SOC. CHEM. IND. (London) Monograph No. 10 (1960), pp. 30-57. Abstr. in CA 54:20786e.
88. Colmer, A. R. "Relation of the iron oxidizer Thiobacillus ferrooxidans to thiosulfate." JOURNAL OF BACTERIOLOGY 83 (April 1962), pp. 761-765. Abstr. in PDC Bi PDL-46363, p. 67.
89. Colomb, P. "Biological corrosion in hydroelectric works in Africa and the action of organic products in this corrosion process." CORROSION ET ANTI-CORROSION 5, No. 5 (1957), pp. 153-155. Abstr. on NACE card 14615.
90. Colomb, P. "Biological corrosion in hydroelectric works in Africa and behaviour of organic products in the corrosion process." PITTURE E VERNICI 14, No. 1 (1958) (in Italian), pp. 69-71. Abstr. on NACE card 17254.
91. Copenhagen, W. J. "The pathology of metals; corrosion of steel and alclad parts by a fungus." METAL IND. (London) 77 (Sept. 1950), p. 137. Abstr. in PDC Bi G-6639, p. 20.
92. Corcoran, E. F., and J. S. Kittredge. "Pitting corrosion of reserve fleet ships." CORROSION PREVENTION AND CONTROL 3, No. 12 (Dec. 1956), pp. 45-48. Abstr. on NACE card 13557 and in PDC Bi G-12405, p. 36.
93. Corrick, J. D., and J. A. Sutton. "Three chemosynthetic autotrophic bacteria important to leaching operations at Arizona copper mines." U. S. Bur. of Mines Rept. Invest. 5718 (1960), 8 pp. Abstr. in CA 55:63051.
94. Coulomb, Pierre. "Biological corrosion in a hydroelectric plant in Africa and role of organic products in the corrosion process." (in Italian) VERNICI 14 (Jan. 1958), pp. 69-71. Abstr. on NACE card 16031.

95. Davies, R. L. "Corrosion Research Laboratories. 10: Cables and Wires, BICC Research." CORROSION TECHNOL. 3 (June 1956), pp. 181-184. Abstr. in PDC Bi G-12807, p. 37.
96. Davy, P. S., "Red Water and Its Prevention." J. AM. WATER WORKS ASSOC. 45, No. 1 (Jan. 1953), pp. 10-18. Abstr. on NACE card 6996 and in PDC Bi G-8945, p. 27.
97. Dechaux, M. G. "Problems of Corrosion and Marine Fouling." PEINTURES PIGMENTS VERNIS 27, No. 5 (1951), pp. 282-286. Abstr. on NACE card 4429.
98. Dechaux, G. and E. Segal. "Seawater corrosion of steel structures." METAUX 29 (1954), pp. 469-482. Abstr. in CA 49:4488f.
99. De Gray, R. J., and L. N. Killian. "Bacterial slime and corrosion in petroleum product storage." IND. ENG. CHEM. 52 (Dec. 1960), pp. 74a-76a. Abstr. in PDC Bi PDL-38654, p. 53.
100. Delahay, P. "A polarographic method for the continuous determination of the consumption of oxygen in corrosion tests." CORROSION 7 (1951), pp. 146-150. Abstr. in CA 45:5091b.
101. Delahay, P. "A polarographic method for the indirect determination of polarization curves for oxygen reduction on various metals. I. Description of the method-case of platinum." J. ELECTROCHEM. SOC. 97 (1950), pp. 198-204. Abstr. in CA 44:6742i.
102. Deuber, C. G. "The present status of bacterial corrosion investigations in the United States." CORROSION 9 (1953), pp. 95-9. Abstr. in CA 47:7989 and in PDC Bi G-8772, p. 26.
103. Deuber, C. G. "Bacterial attack on buried piping regarded as serious cause of rapid corrosion." AM. GAS. J. 178 (1953), pp. 2, 31, 35. Abstr. in CA 47:3781g and in PDC Bi G-9026, p. 28.
104. Dodson, R. E., Jr. "Water heater corrosion studies, with especial consideration to possible bacterial influence." WATER & SEWAGE WORKS 99 (Sept. 1952), pp. 345-349. Abstr. in PDC Bi G-8468, p. 24.
105. Doig, K., and A. Wachter. "Bacterial casing corrosion in the Ventura field." CORROSION 7 (July 1951), pp. 212-224. Abstr. in PDC Bi-G-6982, p. 20.

106. Dontsova, E. I. "Clarification of the oxidation (rusting) process of iron by means of oxygen isotopes." DOKLADY AKAD. NAUK. S.S.S.R. 63 (1948), pp. 305-306. Abstr. in CA 43:2564f.

107. Dostalek, M. "Propane bacteria." CESKOSLOV BIOL. 3 (1954), pp. 162-169. Abstr. in CA 49:4792b.

108. Drabelle, J. M. "Do bacteria cause condenser tube corrosion?" POWER PLANT ENG. 48 (October 1944), pp. 122-124. Abstr. in PDC Bi G-321, p. 8.

109. Drisko, R. W. "Protection of mooring buoys. Part III. Second rating inspection." U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, Technical Report R-291, (24 April 1964).

110. Duchon, K., and L. B. Miller. "The effect of chemical agents on iron bacteria." PAPER TRADE J. 125 (4) (Jan. 1948), pp. 47-48. Abstr. in PDC Bi G-2111, p. 15.

111. Embil y Bollada, J. "Corrosion of iron by sulfur-reducing bacteria in the baths at San Diego de los Baños in Pinar del Rio (Cuba)." ANALES ACAD. CIENC. MED. FIS. Y. NAT. HABANA 93 (1954-55), pp. 257-63. Abstr. in CA 53:2052h.

112. Erisson, G. L., and M. L. Wulf. "Investigation of corrosion and microbiological degradation in integral fuel tanks." BOEING AIRPLANE CO., Wichita Div., Wichita, Kan. Doc. No. D3-3629 (Feb. 1961), 133 p. Abstr. in PDC Ei PDL-41959, p. 57.

113. Farrar, T. W., L. Biek, and F. Wormwell. "The role of tannates and phosphates in the preservation of ancient buried iron objects." J. APPLIED CHEM. 3, Pt. 2 (1953), pp. 80-84. Abstr. on NACE card 6461.

114. Farrar, T. W., and F. Wormwell. "Corrosion of iron and steel by aqueous suspensions of sulphur." CHEMISTRY AND INDUSTRY, No. 5 (Jan. 31, 1953), pp. 106-107. Abstr. on NACE card 6116.

115. Fink, F. W., "Corrosion of metals in sea water." Battelle Mem. Inst., Office of Saline Water Research and Development Progress Rept. No. 46 (Dec. 1960), 62 pp. Abstr. in Corrosion Abstr.

116. Flemming, C. D., and R. J. Baker. "Controlling the spoilage of water-soluble cutting fluids." LUBRICATION ENG. 16 (1960), pp. 414-419. Abstr. in CA 54:25735e.
117. Frenzel, H. J., "Investigations into iron corrosion caused by bacteria." WERKSTOFF u. KORROSION, 16, No. 8 (August 1965), p. 651. Abstr. in Corrosion Abstr. 4 (Nov. 1965), p. 430.
118. Furusaha, C. "Sulfate transport and metabolism by Desulfovibrio desulfuricans." NATURE 192 (1961), pp. 427-429. Abstr. in CA 56:5204g.
119. Garnett, P. H. "Growth of iron bacteria in crude tar." NATURE 185 (March 1960), p. 943. Abstr. in PDL-37921, Vol. 18 (1960).
120. Garnier, C., and C. Magnoux. "Protection of materials and instruments against the principal biological agents of deterioration." (in French) CORROSION ET ANTICORROSION 10 (Jan. 1962) pp. 9-22. Abstr. in Corrosion Abstr. 3 (Jan. 1964), p. 14.
121. Gasanov, M. W. "Formation of H₂S by biological reduction of sulfates during flooding with sea water." NEFT. KHOZ 38, No. 12 (1959), pp. 28-30. Abstr. in CA 55:2076e.
122. Gasanov, M. V. "Sulfate reduction in mixtures of seawater and stratum brines in a hydrogen atmosphere with participation of sulfate-reducers." MIKROBIOLOGIYA 29 (1960), pp. 419-421. Abstr. in CA 54:25719e.
123. Gatellier, C. "Importance of the role of bacteria in corrosion." L'ASSOCIATION FRANCAISE DES TECHNICIENS DE PETROLE." Bulletin No. 152 (March 31, 1962), pp. 293-304. Abstr. in NACE Bulletin.
124. Gatellier, C. "Part played by bacteria in corrosion due to water." CORROSION ET ANTI-CORROSION 11, No. 7-8 (1963), pp. 257-263. Abstr. in Corrosion Abstr. 3 (July 1964), p. 223.
125. Genovese, S. "The bacterial cycle of sulfur." GIORN. MICROBIOL. 5 (1958), pp. 165-175. Abstr. in CA 54:4767f.
126. Gherardi, D., and G. Bombara. "Control of the sulfate-reducing bacteria." ANN. UNIV. FERRARA SEZ 5, Suppl. 1960, (Publ. 1961), pp. 653-669 (in English). Abstr. in CA 56:3891.

127. Gherardi, D., G. Bombara, G. Banfi, and V. Cavazzoni. "Electro-chemistry of sulfate-reducing bacteria. Cathodic control." *RICERCA SCI.* 30 (1960), pp. 711-720. Abstr. in *CA* 55:14587f.
128. Gilbert, P. T. "Corrosion of copper, lead, and lead-alloy specimens after burial in a number of soils for periods up to 10 years." *INST. METALS J.* 73 (Nov. 1946), pp. 139-174. Abstr. in *PDC Bi G-1454*, p. 11.
129. Brabar, P. "Review of the microbiological and immunological literature published in the U.S.S.R." (Institut Pasteur, Paris). *ANN. REV. MICROBIOL.* 10 (1956), pp. 51-84. Abstr. in *CA* 50:16980g.
130. Gr. Brit., Admiralty, Corrosion Committee, Hull Corrosion Subcommittee. "Corrosion of iron and steel associated with the presence of sulphate-reducing bacteria." Report ACC/H105.1 (1946). Abstr. in *PDC Bi G-334*, p. 1.
131. Gr. Brit., Admiralty, Corrosion Committee, Hull Corrosion Subcommittee. "Anaerobic corrosion of mine shells in Malayan waters." Report ACC/H105.3 (1946). Abstr. in *PDC Bi B-336*, p. 1.
132. Gr. Brit., Admiralty, Corrosion Committee, Hull Corrosion Subcommittee. "Corrosion of buried 'Black Iron' water main at R. N. Armament Depot, Umbogintwini Natal." Report ACC/H51 (1947). Abstr. in *PDC Bi B-344*, p. 2.
133. Gr. Brit., Admiralty, Royal Navy Scientific Service. "A bibliography of literature relating to fouling and its prevention." Book at A.C.S.L.I. Library Queen Anne's Mansions, St. James Park, London, S. W. 1, England. (May 1958), 236 pp. Abstr. on NACE card 15708.
134. Gr. Brit., Ministry of Health. "Interim report of the departmental committee on the deterioration of cast iron and spun iron pipes." London. His Majesty's Stationery Office (1950), 53 p. Abstr. in *PDC Bi B-529*, p. 3.
135. Grebski, J. "Bacterial corrosion of concrete and iron." *PRZEMSYL CHEM.* 6 (1950) pp. 105-111. Abstr. from *CA* 45:10179f.
136. Grier, N., and J. A. Ramp. "The control of sulfate-reducing bacteria." *CHEM. SPEC. MFRS. ASSOC. PROC. ANN. MEETING* 49 (1962), pp. 110-120. Abstr. in *CA* 59:1993e.

137. Guynes, G. J., and E. O. Bennett. "Sensitivity of sulfate-reducing bacteria to antibacterial agents." PRODUCER'S MONTHLY 23, No. 1 (1958), pp. 15-17. Abstr. in CA 53:5386d and in PDC Bi PDL-35188, p. 44.
138. Hadley, R. F. "Microbiological anaerobic corrosion . . . of steel pipe lines." OIL GAS J. 38 (19) (Sept. 1939), pp. 92, 94, and 96. Abstr. in PDC Bi X-258, p. 38.
139. Hadley, R. F. "Corrosion by micro-organisms in aqueous and soil environments." Corrosion Handbook, John Wiley and Sons (1948) New York. Edited by H. Uhlig. pp. 466-481.
140. Hadley, R. F. "Methods of studying microbiological anaerobic corrosion of pipe lines." PETROLEUM ENGR. 11 (6): 11 (7): pp. 114-116 and 171-176 (Mar. - Apr. 1940). Abstr. in PDC Bi X-257, p. 38.
141. Harris, J. O. "Soil microorganisms in relation to cathodically protected pipe." CORROSION 16 (Sept. 1960), pp. 113-120. Abstr. in PDC Bi PDL-37588, p. 48.
142. Harris, J. O. "The role of soil microorganisms in corrosion." For presentation at the Seventh Annual Appalachian Underground Corrosion Short Course, West Virginia University, Morgantown, West Virginia (1962), 19 p. Abstr. in PDC Bi PDL-44295, p. 64.
143. Harris, J. O. "Bacterial-environment interactions in corrosion on pipelines: ecological analysis." CORROSION 20, No. 11 (November 1964). Abstr. in Corrosion Abstr. 4 (March 1965), p. 99.
144. Harris, J. O. "Soil micro-organisms in relation to corrosion and cathodic protection." CORROSION TECHNOL. 7 (Aug. 1960), pp. 250-253. Abstr. in PDC Bi PDL-37423, p. 46.
145. Harris J. O. "Soil conditions, bacteria, and corrosion." NACE Convention, March 1962, K. C.M Mo. 23 p. Abstr. in PDC Bi PDL-43822, p. 63.
146. Harris, J. O. "Bacterial activity at the bottom of back-filled pipe-line ditches." CORROSION 16 (Mar. 1960), pp. 149t-154t. Abstr. in CA 54:7499c and in PDC Bi PDL-37587, p. 46.
147. Harrison, A. G., and H. G. Thode. "Mechanism of the bacterial reduction of sulfate from isotope fractionation studies." TRANS. FARADAY SOC. 54 (1958), pp. 84-92. Abstr. in CA 16470d.

148. Hata, Y. "Relation between the activity of marine sulfate-reducing bacteria and the oxidation-reduction potential of the culture media (2)." J. SHIMONOSEKI COLLEGE OF FISHERIES 10 (1) (Oct. 1960), pp. 57-77. Abstr. in PDC Bi PDL-43176, p. 62.
149. Hata, Y. "Hydrogen acceptor in growth and sulfide formation of marine sulfate-reducing bacteria." NORINSHO SUISAN KOSHUSHO KENKU HOKOKU 10 (1960), pp. 79-87. Abstr. in CA 57:14280c.
150. Hata, Y. "Influence of heavy metals upon the growth and the activity of marine sulfate-reducing bacteria." NORINSHO SUISAN KOSHUSHO KENKYU HOKOKU 2 (1960), pp. 363-375. Abstr. in CA 58:11710.
151. Hata Y. "Response of marine sulfate-reducing bacteria to the salinity of culture medium." NORINSHO SUISAN KOSHUSHO HOKOKU 2 (1960), pp. 329-345. Abstr. in CA 58:11710f.
152. Hata, Y., H. Myoshi, H. Kadota, and M. Kimata. "Marine sulfate-reducing bacteria. VII. Relation between the activity of marine sulfate-reducing bacteria and the oxidation-reduction potential of the culture media." NORINSHO SUISAN KOSHUSHO KENYU HOKOKU 8 (Dept. of Forestry-Fisheries Dept.) Report 8 (1959), pp. 135-145. Abstr. in CA 55:9571h.
153. Hendey, N. L. "Littoral diatoms of Chichester harbour with special reference to fouling." J. ROYAL MICROSCOPICAL SOC. 71, Part 1 (1951), pp. 1-86. Abstr. on NACE card 4659.
154. Hendy, N. I. "Some observations on Cladosporium resinae as fuel contaminant and possible role in corrosion of aluminum alloy fuel tanks." BRIT MYCOL. SOC. 47, No. 4 (1964), pp. 467-475. Abstr. in Corrosion Abstr. 4 (Sept. 1965), p. 345.
155. Higgins, W. F. "The present status of bacterial corrosion investigations in the U. S." CORROSION 9 (1953), pp. 243-244. Abstr. in CA 47:7989.
156. Hitzman, D. O. "Bactericidal compositions from tetra-alkyl quaternary ammonium halides and hydrogen peroxide." US Pat. No. 2,917,428 (Dec. 15, 1959). Abstr. in CA 54:8049d.
157. Hitzman, D. O., and R. P. Schneider. "Microbiological corrosion protection by germicidal zone and protective coating." US Pat. No. 2,979,377 (April 11, 1961). Abstr. in PDC Bi PDL-40348, p. 53.

158. Hoar, T. ., and T. W. Farrar. "The anodic characteristics of mild steel in dilute aqueous soil electrolytes." CORROSION SCI 1 (Aug. 1961), pp. 49-61.
159. Horio, T., and M. D. Kamen. "Preparation and properties of three pure crystalline bacterial hem proteins." BIO-CHEM ET BIOPHYS. ACTA. 48 (1961), pp. 266-286 (in English). Abstr. in CA 55:24861h.
160. Horvath, J. "Contributions to the mechanism of anaerobic microbiological corrosion." ACTA CHEM. ACAD. HUNG. 25 (1960), pp. 65-78. Abstr. in PDC PDL-46761, p. 68.
161. Horvath, J. "Mechanism of anaerobic microbiological corrosion. I. Interpretation of the effects of sulfate-reducing bacteria on the basis of polarization curves." MAGY. KEM. FOLYOIRAT 68, No. 1 (1962), pp. 5-9. Abstr. CA 57:9569h.
162. Horvath, J. and M. Novak. "The mechanism of anaerobic microbiological corrosion." ACTA. CHIM. ACAD. SCI. HUNG. 33 (1962), pp. 211-235 (in English). Abstr. in CA 58:2133g and in PDC Bi PDL-41557, p. 55.
163. Horvath, J. and M. Solti. "The mechanism of anaerobic microbiological corrosion of metals in soil." WEKSTOFFE U. KORROSION 10 (Oct. 1959), pp. 624-630. Abstr. in PDC Bi PDL-36077, p. 45.
164. Hunter, J. B., H. G. McConomy, and R. F. Westen. "Environmental pH as a factor in control of anaerobic bacterial corrosion." CORROSION 4 (1948), pp. 567-80. Abstr. in CA 43:547b and in PDC Bi G-3488, p. 16.
165. Ikemura, K. "Corrosion and its prevention of copper alloys in polluted sea water." (in Japanese) CORROSION ENGINEERING (Japan) 11 (1962), pp. 250-255. Abstr. in CA 4.6.11. (Corrosion Abstracts).
166. International Nickel Co. Inc., New York, N. Y. Development and Research Division. "Record of discussions at sea horse institute informal conference, June 1950." (Oct. 1951), 58 pp. Abstr. in PDC Bi C-1060, p. 4.
167. Irwin, Margaret. "Steel-boring sea urchins." PACIFIC DISCOVERY VI, No. 2 (March-April 1953), pp. 26-27.
168. Ishimoto, M. and S. Shimoto. "Sulfate-reducing bacteria. X. Adenosine-5'-phosphate reductase." J. BIOCHEM. (Tokyo) 50 (1961), pp. 229-237. Abstr. in CA 56:10562i.

169. Ishimoto, M., Y. Kondo, T. Kameyama, T. Yagi, and M. Shiraki. "Role of cytochrome in the enzyme system of sulfate-reducing bacteria." Proc. Intern. Sym. Enzyme Chem., Tokyo and Kyoto 2 (1957), pp. 229-39. Abstr. in CA 54:4773c.
170. Ishimoto, M. and J. Koyama. "Sulfate-reducing bacteria. VI. Separation of hydrogenase and thiosulfate reductase, and partial purification of cytochrome and green pigment." J. BIOCHEM. (Tokyo) 44 (1957), pp. 233-242. Abstr. in CA 51:13052i.
171. Ishimoto, N. J., J. Koyama, T. Yagi and M. Shiraki. "Sulfate-reducing bacteria. VII. Purification of the cytochrome of sulfate-reducing bacteria and its physiological role." J. BIOCHEM. (Tokyo) 44, pp. 413-423. Abstr. in CA 51:16670h.
172. Ishimoto, M. and T. Yagi. "Sulfate-reducing bacteria. IX. Sulfate-reductase." J. BIOCHEM. (Tokyo) 49 (1961), pp. 103-109. Abstracted in CA 55:16652c.
173. Ishimoto, M., T. Yagi, and M. Shiraki. "Sulfate-reducing bacteria. VIII. The function of cytochrome of sulfate-reducing bacteria in decomposition of formate and reduction of sulfur hydroxylamine." J. BIOCHEM. 44 (1957), pp. 707-714. Abstr. in CA 52:3906a.
174. Johnston, R. K., F. W. Bieberdorf, R. G. Weichlein, J. C. Tyler, and R. D. Brown. "A study of existing base fuel handling procedures in relation to microbial contamination." Southwest Research Inst., San Antonio, Tex., 278 pp. (June 1964). Contract AF33 657 9762, Proj. 8169, Task 816906, SEG TDR 64 29, Order AD-603 852 from OIS, \$6. Abstr. in Corrosion Abstr. 4 (March 1965), p. 99.
175. Jones, G. E. "Fractionation of the stable isotopes of sulfur by micro-organisms with particular reference to the sulfate-reducing bacteria." Univ. Microfilms (Ann Arbor, Mich.), Publ. No. 16680, 195pp. Dissertation Abstract 16, p. 1317-18 (1956). Abstr. in CA 50:16983a.
176. Jones, G. E., and R. L. Starkey. "Surface-active substances produced by Thiobacillus thiooxidans." J. BACTERIOL. 82 (Nov. 1961), pp. 788-789. Abstr. in PDC Bi PDL-42625, p. 58.
177. Kalakutskia, L. V. "On the role of micro-organisms in the processes of iron reduction in the soil." (in Russian) NAUK. DOKLADY VYSSHEI SHKOLY, BIOL. NAUKI NO. 1 (1959), pp. 225-229. Abstr. in BIL-36394, Vol. 17 (1960), Biol. 53.

178. Kalinenko, V. O., "Does chemosynthesis occur in iron bacteria and nitrifiers?" *MIKROBIOLOGIYA* 25 (1956), pp. 342-362. Abstr. in CA 50:16981i.
179. Kalinenko, V. O. "Bacterial colonies on metal plates in seawater." *MIKROBIOLOGIYA* 28 (Sept./Oct. 1959), pp. 750-756. Abstr. in PDC Bi PDL-37684, p. 48.
180. Kalinenko, V. O., and N. A. Mefedova. "Bacterial fouling of the submerged parts of ships (in Russian with English summary)." (1956), pp. 191-194. Abstr. in PDC Bi PDL-31860, p. 41.
181. Kimata, M., H. Kadota, Y. Hata, H. Miyoshi. "Marine sulfate-reducing bacteria. VI. Production of sulfides in the estuarine region of the river receiving a large amount of organic drainage." *NIPPON SUISANGAKU KAISHI* 22 (1957), pp. 701-707. Abstr. in CA 52:14909h.
182. Kinsel, Norma A. "Autotrophic bacterium oxidizing ferrous ion and elemental sulfur in acid media." *DISSERTATION ABSTR.* 20 (1959), pp. 1533-4. Abstr. in CA 54:3585f.
183. Knight-Jones, E. W., and D. J. Crisp. "Gregariousness in barnacles in relation to the fouling of ships and to anti-fouling research." *NATURE* 171 (June 20, 1953), pp. 1109-1110. Abstr. on NACE card No. 8982.
184. Knowles, E., and T. White. "The protection of metals with tannins." *OIL AND COLOUR CHEMISTS ASSOC. J.* 41 (Jan. 1958), pp. 10-23. Abstr. in PDC Bi PDL-32958, p. 43.
185. Krasna, A. I., E. Riklis, and D. Rittenberg. "Purification and properties of the hydrogenase of *Desulfovibrio desulfuricans*." *J. BIOL. CHEM.* 235 (1960), pp. 2717-2720. Abstr. in CA 54:25048d.
186. Kravtsov, P. V., and Yu I. Sorokin. "Hydrogen sulfide formation by reduction of sulfites in Kuibyshev reservoir." *AKAD. NAUK SSSR* (1959), No. 2, pp. 191-192. Abstr. in CA 55:4332b.
187. Kreuger, Walter. Principles of microbiology. 2nd printing. W. B. Saunders & Co., Phila. and London. pp. 110-111, 114-115, 116, 322, 323.
188. Kriss, A. P. "Microbiology and the chief problems in the Black Sea." *DEEP SEA RESEARCH* 2 (March 1959), pp. 193-200. Abstr. in PDC-1959.

189. Kuhr, C. A., H. Von Wolzogen, and L. S. Van der Vlugt. "Aerobic and anaerobic iron corrosion in water mains." J. AM. WATER WORKS ASSOC. 45 (Jan. 1953), pp. 33-46. Abstr. in PDC Bi G-8941, p. 27.
190. Kulman, F. E. "Microbiological corrosion of buried steel pipe." CORROSION 9, No. 1 (1953), pp. 11-18. Abstr. in PDC Bi G-8613, p. 25.
191. Kuznetsov, S. I., and E. S. Pantskhava. "Increase of the electrochemical corrosion caused by a methane generating bacteria (in Russian)." DOKLADY AKADEMII NAUK S.S.S.R. 139 (Feb. 1961), pp. 478-480. Abstr. in NACE bulletin.
192. Kuznetsov, U. V., and L. V. Verzhbitskaya. "Role of microorganisms in iron corrosion in water." MICROBIOLOGY 30 (Nov./Dec. 1961), pp. 436-438. Abstr. in PDC Bi PDL-43205.
193. Kuznetsova, V. A. "Occurrence of sulfate-reducers in oil-bearing strata of the Kuibyshev as related to salt composition of stratum brines." MIKROBIOLOGIYA 29 (1960), pp. 408-414. Abstr. in CA 54:214182e.
194. Lagarde, E. "Studies on the bacteriostatic and bactericidal activities of certain compounds against a pure strain of Desulfovibrio desulfuricans." ANN. INST. PASTEUR 100 (1961), pp. 368-376. Abstr. in PDC Bi PDL-42666, p. 59.
195. Lanigan, S. M. R., and K. E. Anderson. "The isolation and cultivation of Desulfovibrio desulfuricans." Paper presented at the Regional Meeting of the Central New York Branch, American Society for Microbiology (Nov. 18, 1961).
196. Lazaroff, N. "Sulfate requirement for iron oxidation by Thiobacillus ferrooxidans." J. BACTERIOL. 85 (Jan. 1963), pp. 74-83. Abstr. in PDC Bi PDL-47403, p. 69.
197. Leathen, W. W., L. D. McIntyre, and S. A. Braley. "A medium for the study of the bacterial oxidation of ferrous iron." JOURNAL 114, pp. 240-241. Abstr. in PDC Bi PDL-48911, p. 10.
198. Le Ferrvo, F. J., and L. F. Surratin. "Some observations of the effect of cathodic protection on rust-inhibitor pi." J. NEW ENGLAND WATER WORKS ASSOC. 14 (Dec. 1961), pp. 321-322. Abstr. in PDC Bi G-6677, p. 2.

199. Liberthson, L. "Effect of sulfur bacteria on corrosion." IRON STEEL ENG. 24, No. 6 (1947), pp. 69-73. Abstr. in CA 41:5083g.
200. Logan, K. H. "Underground corrosion." U. S. Govt. Prtg. Office, Wash. D. C. (Nov. 27, 1945), 1 p. Abstr. in PDC Bi G-634, p. 8.
201. London, J. "Cytochrome in Thiobacillus thiooxidans." SCIENCE 140 (1963), pp. 409-410. Abstr. in CA 59:5520e.
202. Lyalikova, N. N. "The physiology and ecology of Thiobacillus ferrooxidans in relation to its role in the oxidation of sulfid-ores." REV. MICROBIOLOGY 29 (Mar.-Apr. 1961), pp. 556-560. Abstr. in PDC Bi PDL-41985, p. 58.
203. Lytle, M. L. "Corrosion inhibition." U. S. Pat. No. 2,723,233 (Nov. 8, 1955) (to Esso Research & Eng. Co.). Abstr. in CA 50:6287f.
204. Magilevskii, G. A. "Soil analysis for bacteria in bacterial oil prospecting." USSR Pat. Nl. 67,609 (Dec. 31, 1946). Abstr. in CA 43:3185c.
205. Marchlewitz, B., D. Hasche, and W. Schwartz. "Investigations on the behavior of thiobacteria against heavy metals." ALLGEM. MIKROBIOL. 1 (1961), pp. 179-191. Abstr. in CA 56:5205c.
206. Matthews, A. D., and P. N. Karnachow. "A simple technique for the cultivation of anaerobes." CAN. MED. ASSOC. J. 84 (1961), pp. 793-794. Abstr. in PDC Bi PDL-41642, p. 55.
207. McComb, G. B. "A collection of papers on underground pipeline corrosion with special emphasis on cathodic protection and its effect on design, operating, and maintenance costs." Vol. III (1959); Vol. IV (1960); Vol. V (1961). Abstracted in PDC Bi PDL-42848, and PDL-42849, p. 60.
208. McGregor, J. M. "Microorganisms fail to grow in furane-lined jet fuel storage tanks." MATERIALS PROTECTION 2 (June 1963), pp. 24-26, 28. Abstr. in PDC Bi PDL-48220, p. 70.
209. Mechalas, B. J. "Energy coupling in Desulfovibrio desulfuricans." DISSERTATION ABSTR. 20 (1959), p. 33. Abstr. in CA 53:18182g.

210. Miller, R. N., W. C. Herron, A. G. Krigrens, J. L. Cameron, and B. M. Terry. "Micro-organisms cause corrosion in aircraft fuel tanks." MATERIALS PROTECTION 3, No. 9 (September 1964), pp. 60-67. Abstr. in Corrosion Abstr. 3 (Nov. 1964), p. 391.
211. Miller, S. "Why shipbottom paints fail." SEA FRONTIERS. 4, No. 1 (Feb. 1958), pp. 13-22. Abstr. on NACE card 15470.
212. Minchin, L. T. "Bacterial corrosion of underground pipes." COKE AND GAS (England) 22 (Sept. 1960), pp. 392-397, 411. Abstr. in PDC Bi PDL-40400, p. 54.
213. Minchin, L. T. "Corrosion of pipes by bacteria." GAS AGE Vol. 114 (Oct. 7, 1954), pp. 45-47. Abstr. on NACE card No. 8672 and in PDC Bi G-10723, p. 33.
214. Mitchell, A. R. "Iron bacteria in gasholder water." GAS J. 281 (Mar. 1955), pp. 845-847. Abstr. on NACE card 9618.
215. Moehrl, K. E. "Corrosion attack in water wells." CORROSION 17 (Feb. 1961), pp. 26-27. Abstr. in PDC Bi PDL-41295, p. 55.
216. Moore, B. H. "How to solve bacterial problems in waterflood operations." WORLD OIL 158, No. 4 (March 1963), pp. 100-110. Abstr. in Corrosion Abstr. 3 (Sept. 1964), p. 306.
217. Morgan, J. D., and R. E. Lowe. "Corrosion inhibiting compounds." U. S. Pat. No. 2,566,168 (Aug. 28, 1951), 3 p. Abstr. in PDC Bi P-2025, p. 37.
218. Munger, C. G. "Sewer corrosion and protective coatings." CIVIL ENG., Vol. 30, No. 5 (1960 - May), pp. 57-59. Abstr. on NACE card 20352.
219. Muraoka, J. S. "The effects of marine organisms on engineering materials for deep-ocean use." US NCEL IR-182 (March 1962), 40 p. Abstr. in PDC Bi PDL-43947, p. 64.
220. National Research Council, Prevention of Deterioration Center, Washington, D. C., Publication 514, Conference Proceedings, "Metal metabolism and microbiological deterioration." (June 1956). Abstr. in PDC Bi PDL-31125, p. 41.
221. National Research Council, Prevention of Deterioration Center, Washington, D. C., Search No. 62-012. "Microbiological activity at deep sea and its effect on materials." Compiled by Richard W. H. Lee (March 1962).

222. National Research Council, Prevention of Deterioration Center, Washington, D. C., Search No. 63-025. "Bibliography on microbial corrosion of metals." Compiled by Richard W. H. Lee (July 1963).
223. National Research Council, Prevention of Deterioration Center, Washington, D. C., Search No. 61- . "Bibliography on microorganisms affecting petroleum and petroleum products including reports on sulfate-reducing bacteria." Compiled by Richard W. H. Lee (August 1961).
224. Neilands, J. B. "Early stages in the metabolism of iron." HAEMATIN ENZYMES SYMP. INTERN. UNION BIOCHEM., Canberra, 1959 1 (1961), pp. 194-206. Abstr. in CA 58:12879a.
225. Nelson, E. E. "Micro-biological corrosion in waterfloods." CORROSION 18 (1962), pp. 247t. Abstr. in CA 57:9572c.
226. Neujahr, H. Y. "Vitamins in sewage sludge. X. Production of vitamin B-12 by sulfate-reducing bacteria." ACTA. CHEM. SCAND. 13 (1959) (in English), pp. 1960-76. Abstr. in CA 56:14716e.
227. Nicholls, J. H. "The hot-dip galvanized coating and corrosion resistance." Part 1. CORROSION TECHNOL. 6 (Sept. 1959), pp. 275, 276-284. Abstr. in PDC Bi PDL-35821, p. 45.
228. Nicolaus, H. O. "Corrosion by microorganisms." ZEITSCHRIFT DES VEREINES DEUTSCHER INGENIEURE Vol. 94 (1962), pp. 39 (Jan. 11). Abstr. on NACE card 4218.
229. Nikitina, N. S. and I. B. Ulanovskii. "Microbiological factors of steel corrosion in sea water." TRUDY MURMANSK BIOL. STA., AKAD NAUK. S.S.S.R. KOLS'K. FILIAL 3 (1957), pp. 190-199. Abstr. in CA 53:1068e.
230. Ogusi, Z., O. Kawada, and T. Miyasita. "Study on the effects of cathodic electric current on fouling resistance of shipbottom paint." J. JAPAN SOC. COL. "AT., 32, No. 4 (1959), pp. 140-142. Abstr. on NACE card 20917.
231. Olsen, E., and W. Szybalski. "Aerobic microbiological corrosion of water pipes." Parts I and II. CORROSION 6, No. 12 (Dec. 1950), pp. 405-414. Abstr. in PDC Bi G-6308, p. 19.
232. Oppenheimer, C. H. "How to detect and control corrosion-causing bacteria." WORLD OIL. Vol. 147, No. 7 (1958 - Dec.), pp. 144-147. Abstr. on NACE card 17532.

233. Oppenheimer, C. H., Charles Willingham, and R. Beal. "Activities of Hydrogen in marine environments and the corrosion of iron." Marine Lab., Univ. of Miami, Coral Gables, Fla., Annual Progress Report, (1963). Contract Nonr4008 06, Proj. NR103 543 ML 64088, Order AD-433 549 from OTS. Abstr. in Corrosion Abstr., 4, (Jan. 1965) p. 14.
234. Otsu, Takemichi and S. Sata. "Corrosion testing on condenser tubes by model condenser at Osaka power station." (Rep. 2) SUMITOMO LIGHT METAL TECH. REPORTS, 2, (April 1916) pp. 23-34. Abstr. in PDC Bi PDL-43043, p. 61.
235. Parker, C. D., "Bacterial corrosion of construction materials." COMMONWEALTH ENGR. Vol. 39, No. 5 (1951) pp. 190-196. Abstr. on NACE card 4833.
236. Parker, W. D. and A. G. Wilkie. "Anti-corrosion coatings for buried pipes." Proceedings of the Corrosion convention. 1957. (1958) 7p. Abstr. in PDC Bi PDL-33439, p. 44.
237. Partington, A. "Effects of fouling and its economic importance." Part I. CORROSION TECHNOL. 8, (June 1961) pp. 176-179. Abstr. in PDL-41219. Vol. 19, 1961.
238. Patterson, W. S., "Corrosion due to mud banks in river estuaries." J. APPLIED CHEM., 4, (Dec. 1954) pp. 661-666. Abstr. on NACE card 8609
239. Patterson, W. S., "Ship corrosion due to bacterial action." TRANS. NORTH EAST COAST INST. ENGRS. & SHIP-BUILDERS, Vol. 68, No. 2 (1951) pp. 93-106. (Dec.) Abstr. on NACE card 4873 A. and in PDC B: G-8347, p. 23.
240. Payer, A. "Biological corrosion of steel pipelines." (For gas), PALIVA Vol. 41, (1961) pp. 183-190. Abstr. in PDL-43135, Aug. 1962.
241. Peabody, A. W. "Pipeline corrosion survey techniques." MATERIALS PROTECTION, 1, (April 1962) pp. 66, 68, 70, 71, 76. Abstr. in PDC Bi PDL-43646, p. 63.
242. Peck, Harry D. Jr. "The adenosine triphosphate dependent reduction of sulfate with hydrogen in extracts of Desulfo desulfuricans." PROC. NATL. SCI. US 45 (1959) pp. 701-708. Abstr. in CA 54:4757a.
243. Peck, H. D. Jr., "Evidence for oxidative phosphorylation during the reduction of sulfate with hydrogen by Desulfovibrio desulfuricans." J. BIOL. CHEM., 235, pp. 2734-2738. (1960). Abstr. in CA 54-25049g.

244. Peck, H. D. Jr. "Role of adenosine 5'-phosphosulfate in the reduction of sulfate to sulfite by Desulfovibrio desulfuricans." J. BIOL. CHEM. 237, (1962) pp. 198-203, Abstr. in CA 56:10687c.
245. Peck, H. D. Jr. "Enzymatic basis for assimilatory and dissimilatory sulfate reduction." J. BACTERIOL., 82, (Dec. 1916) pp. 933-939. Abstr. in PDC Bi PDL-43035, p. 61.
246. Pelcak, E. J. and Albert C. Dornbush. "Bactericides for water for Ind. use." (to Amer. Cyanamid Co.) US Pat. No. 2,906,595. Sept. 29, 1959. Abstr. in CA 54:1780g.
247. Plummer, F. B. and I. W. Walling. "Reduction of sulfates in oil-field waters." OIL WEEKLY, 121, (Mar. 4, 1946) p. 54. Abstr. in NACE Bibliography.
248. Plummer, F. B. and I. W. Walling. "Reduction of sulfates in oil-field waters." PETROLEUM ENGINEER, REF. ANNUAL (1946) pp. 169-172. Abstr. in NACE Bibliography.
249. Pomortseva, N. V. and V. M. Senyukov. "Effect of antibiotics on sulfates-reducing bacteria." MIKROBIOLOGIYA, 32, No. 1, (1963) pp. 131-135. Abstr. in CA 59:1995e.
250. Postgate, J. "Sulfate reduction bacteria." ANN. REV. MICROBIOL., 13, (1959) pp. 505-520. Abstr. in PDC Bi PDL-38961, p. 53.
251. Pringsheims, E. G. "Iron organisms." ENDEAVOUR No. 11, No. 44 (1952) pp. 208-214. Abstr. on NACE card.
252. Pritula, V. A. "The biocorrosion of underground pipelines." GAZOVAYA PROM., 6, No. 8 (1961) pp. 46-50. Abstr. in CA 55:25699b and in PDC Bi +DL-42735, p. 59.
253. Pryor, M. J. and M. Cohen, "Role of dissolved oxygen during the inhibition of the corrosion of iron by sodium phosphate solutions. NATURE,167, (1951) pp. 157). Abstr. in CA 45:5598c.
254. Pyefinch, K. A. "Studies on marine fouling organisms." J. IRON STEEL INST. (London), 165, (June 1950) pp. [14-[[0. Abstr. in NACE Bibliography.
255. Rabate, H. "Marine underwater paints." PEINTURES, PIGMENTS VERNIS., 27, No. 10 (1951) pp. 619-628. Abstr. on NACE card 4935.

256. Ragg, M. "The occurrence of fouling organisms in plankton." FARBE U LACK, 56, (1950) pp. 530-7. Abstr. in CA 45:3176d.
257. Ragg, M. "Influence of the surface and surface reactions on the fouling of ship bottoms." FARBE U LACK, 59, No. 1, (1953) pp. 17-20. Abstr. on NACE card 6585A.
258. Ranucci-Gatto, L. "Preliminary research on the possible influence of bacterial metabolism on the corrosion of aluminum by stagnating water." ALLUMINIO, 23, (July 1954) pp. 399-411. Abstr. in PDC Bi F-862, p. 7.
259. Reid, R. W., C. E. ZoBell, and C. E. Oppenheimer. "Microbes with an appetite for iron.: RESEARCH REVIEWS (ONR) (May 1955) 1p. Abstr. in PDC Bi G-11316, p. 34.
260. Rigdon, J. H., and C. W. Beardsley. "Corrosion of concrete by autotrophs." CORROSION, 14, No. 4 (April 1958) pp. 206t-208t. Abstr. on NACE card 15116.
261. Rogers, T. H. "The promotion and acceleration of metallic corrosion by microorganisms." J. INST. OF METALS, 75, No. 1 (Sept. 1948) pp. 19-38. Abstr. in PDC Bi G-4200, p. 18.
262. Rogers, T. H. "Biological Corrosion," Marine Corrosion Handbook. McGraw Hill, pp. 43-47.
263. Rogers, T. H., "A method for assessing the relative corrosion behavior of diff. seawaters." J. INST. METALS, 76, (1950) pp. 597-611.
264. Rogers, T. H. "Corrosion of Metals. Influence of Micoorganisms." METAL IND. (London), 73, (1948) pp. 403-405. Abstr. in CA 45:5599g.
265. Rogowski, R. R., and R. N. Brown. "Project bears (bacterial effects, aircraft refueling systems)." U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., Technical Report 1789-TR, (Oct. 1964).
266. Roy, K., M. Sarkar, and B. Chatterjee. "Underground corrosion of metals and alloys. Part II. Behavior of five indian soils in modified denison cell." INDIAN J. APPL. CHEM., 24, (1961), pp. 113-118. Abstr. in PDC Bi PDL-44680, p. 65.

267. Rozenberg, L. A. "The role of bacteria in electrochemical corrosion of steel in sea water." Foreign Tech. Div., Air Force Systems Command, Wright Patterson AFB, Ohio, 16 pp. (June 1964). FTD 393; TT 64 11858, Order AD-602 332 from OTS. Abstr. in Corrosion Abstr., 4, (March 1965) p. 100.
268. Rozenberg, L. A. "Role of sulfate-reducing bacteria on the corrosion of low-alloy and stainless steel in sea." (in Russian). AKAD. NAUK SSSR INST. OKEANOL., TRUDY, 49, (1961) pp. 258-265. Abstr. in PDC Bi PDL-45027, p. 67.
269. Rozenberg, L. A., I. M. Korovin, and I. B. Ulanovskii. "Effect of bacteria on the corrosion of stainless steel." (in Russian). AKAD. NAUK. SSSR INST. OKEANOL., 49, (1961) pp. 248-257. Abstr. in PDC Bi PDL-45026, p. 66.
270. Rozenberg, L. A., and I. B. Ulanovskii. "Growth of bacteria during cathode polarization of steel in seawater." MICROBIOLOGY, 29, (March/April 1961) pp. 521-523. Abstr. in PDC Bi PDL-41985, p. 58.
271. Rozenberg, L. A., I. B. Ulanovskii, and Y. M. Korovin. "Influence of bacteria on corrosion of stainless steel in small openings." NAUK SSSR, 125, (1959) pp. 909-912. Abstr. in CA 53:17376i. Abstr. on NACE card 20830.
272. Rychtera, and E. Niederfuhrova. "Simulating natural microbial corrosion in laboratory." TECHNICAL DIGEST, 7, No. 4 (April 1965). Abstr. in Corrosion Abstr., 4, (July 1965) p. 264.
273. Sadana, J. C., and A. V. Morey. "Purification and properties of the hydrogenase of Desulfovibrio desulfuricans." BIOCHEM. ET. BIOPHYS. ACTA, 50, (1961) (in English) pp. 153-63. Abstr. in CA 56:695e.
274. Saxena, B. B. L., S. S. Nigam, and S. R. Sengupta. "Fungal attack of optical instruments and its prevention." INDIAN J. TECHNOL., 1, No. 7, (1963) pp. 283-286. Abstr. in Corrosion Abstr., 3, (Nov. 1964) p. 391.
275. Schaeffer, W. I. and W. W. Umbreit. "Phosphatidylinositol as a wetting agent in sulfur oxidation by Thiobacillus thiooxidans." I. BACTERIOL, 85, (Feb. 1963) pp. 492-493. Abstr. in PDL-47961.

276. Scott, W. R. "Bacterial corrosion in waterflood systems." MATERIALS PROTECTION, 4, No. 2, (Feb. 1965). Abstr. in Corrosion Abstr., 4, (June 1965) p. 178.
277. Seelmeyer, Gunther. "The biological corrosion of iron." (in German) WEEKSTOFFE U. KORROSION, 4, No. 7 (July 1953) pp. 241-247. Abstr. in PDC Bi F-746, p. 5.
278. Senez, J. C. "The growth of Sporovibrio desulfuricans on sodium pyruvate and lactate." AMER. INST. PAST., 80, (1951) pp. 395-408. Abstr. in CA 46:9152c.
279. Senez, J. C. "The current status of marine bacteriology." LULL. MUS. NAT. HIST., MARSEILLE., 8, (1948) pp. 151-176. Abstr. in CA 46:9664b. (cf. 45:9611c-"Current status of marine bacteriology." BULL. MUS. HIS. NAT. MARSEILLE, 8, (1948) pp. 128-150.
280. Senez, J. C. "Consumption of molecular hydrogen by non-proliferating suspensions and by cell extracts of Desulfovibrio desulfuricans." BULL. SOC. CHEM. BIOL., 37, (1955) pp. 1135-1146. Abstr. in CA 50:8794.
281. Senez, J. C. "Investigation on biological corrosion in anaerobic soils by sulfate-reducing bacteria." CORROSION ET ANTI-CORROSION, 1, (Nov.-Dec. 1953), pp. 131-132. Abstr. on NACE card 9071 and in PDC Bi F-818, p. 6.
282. Senez, J. C. "Metabolism of amino-acids and amides by sulfates reducing bacteria." CONGR. INTERN. BIOCHIM, RESUMES COMMUNS., 2 CONGR., (Paris) 1952. p. 94. Abstr. in CA 49:7648b.
283. Senez, J. C. "Metabolism of amino acids and acid amides by sulfate-reducing bacteria." ANN. INSI. PASTEUR, 83, (1952) pp. 786-90. Abstr. in CA 47:3919a.
284. Senez, J. C., and J. Lerous-Gilleron. "Preliminary note on the anaerobic degradation of cysteine and cystine by sulfate-reducing bacteria." BULL SOC. CHIM BIOL., 36 (1954) pp. 552-559. Abstr. in CA 49:421i.
285. Senez, J. C. "Fermentation of pyruvic acid and dicarboxylic acids by sulfate-reducing anaerobic bacteria." BULL SOC. CHIM. BIOL., 36, (1954) pp. 541-552. Abstr. in CA 49:421g.

286. Senez, J. C., and M. C. Pascal. "Degradation of choline by sulfate-reducing bacteria. Identification of Desulfovibrio desulfuricans and Vibrio cholonicus." Z. ALLGEM. MICRO BIOL. 1, (1961) pp. 142-149. Abstr. in CA 55:24930d.
287. Senez, J. C., and B. E. Volcani. "Utilization of molecular H by pure cultures of sulfate-reducing bacteria of marine origin." COMPT. REND., 232, (1951) pp. 1035-1036. Abstr. in CA 45:7636c.
288. Sharpley, J. M. "Microbiology can pinpoint corrosion." PET. WEEK, (Nov. 11, 1960).
289. Sharpley, J. M. "Elementary hydrocarbon microbiology." Final report, Contract AF 33(657)-10865, Sharpley Labs., Inc., Fredericksburg, Va., 310 pp., (April 1964). ASD-TDR-63-752; AD-600232, order from OTS. Abstr. in Corrosion Abstr., 4, (Jan. 1965) p. 14.
290. Sharpley, J. M., "Microbiological corrosion in waterfloods." CORROSION Vol. 17, No. 8 (1961) pp. 386t-390t. Abstr. on NACE card No. 22168 and in PDC Bi PDL-41247, p. 54.
291. Sharpley, J. M. "New type of iron bacteria found in salt water." OIL AND GAS. J., Vol. 4 (1959) pp. 89-90. Abstr. on NACE card 21947.
292. Sharpley, J. M. "The occurrence of Gallionella in salt water." APPLIED MICROBIOL. 9, (Sept. 1961) pp. 380-382. Abstr. in PDC Bi PDL-41929, p. 57.
293. Sherwood, P. W. "Watch out for bacterial corrosion in the refinery." CORROSION TECHNOL. 9, (Aug. 1962) pp. 211-214. Abstr. in PDC PDL-45722, p. 67.
294. Sherwood, P. W. "Control of bacteriological corrosion in (oil) refineries." CORROSION ANTI-CORROSION, 11, No. 2, (1963) pp. 56-62. (in French). Abstr. in CA 59:1417d.
295. Sigal, N., J. C. Senez, J. Le Gall, and M. Sebald. "Base composition of the deoxyribonucleic acid of sulfate-reducing bacteria." J. BACTERIOL., 85, (1963) pp. 1315-18. Abstr. in CA 59:1977f.
296. Signorelli, G. "Corrosion phenomena in large metallic structure." METALLURGIA ITALIANA, 55, No. 7, (July 1963) pp. 327-332. (in Italian). Abstr. in Corrosion Abstr., 3, (Nov. 1964) p. 391.

297. Silverman, M. P., and D. G. Lundgren. "The chemo-autotrophic iron bacterium, Ferrobacillus ferrooxidans. II. Manometric Studies." J. BACTERIOL., 78, (1959) pp. 326-331. Abstr. in CA 10053a (1960).
298. Silverman, M., and D. Lundgren. "Studies on the chemoautotrophic iron bacterium Ferrobacillus ferrooxidans. I. An improved medium for the obligate chemoautotrophic Fe bacterium." J. BACTERIOLOGY, 77, (1959) pp. 642-7. Abstr. in CA 53:15200b.
299. Silverman, M. P., and M. H. Rogoff. "Morphological variation in Ferrobacillus ferrooxidans related to the rate of iron oxidation." NATURE., 191, pp. 1221-1222. Abstr. in CA 56:9218b.
300. Sisler, F. D., and C. E. Zobell. "Hydrogen utilization by some marine sulfate-reducing bacteria." J. BACTERIOL., 62, (1951) pp. 117-127.
301. Skerman, T. M. "The nature and development of primary films on surfaces submerged in the sea." NEW ZEALAND JOURNAL OF SCIENCE AND TECHNOLOGY, 38, B (July 1956).
302. Skipp, B. O. "Corrosion and site investigation." CORROSION TECHNOL., 8, (Sept. 1961) pp. 269-277. Abstr. in PDC Bi PDL-41699, p. 55.
303. Snoke, L. R. "Marine tests of organic materials." BELL LABS RECORD, 35, No. 8, (Aug. 1957) pp. 287-292. Abstr. on NACE card 15075.
304. Snyder, J. A., and D. Warren. "Corrosion in hydrogensulfide water systems." Report of US Atomic Energy Comm., DP-96-(1955). 240 pp. Abstr. in CA 54:20786b.
305. Sokolova, G. A. "Iron bacteria of Lake Glubokoe." MICROBIOLOGY, 28, (Jan./Feb. 1959) pp. 75-79. (Trans. of Mikrobiologiya, USSR). Abstr. in PDL-40772. Vol. 19- Biol. 18, (1961).
306. Solti, M., and J. Horvath. "The influence of anaerobic bacteria on the current density of cathodically protected equipment in soils." WERKSTOFF U. KORROSION, 9, (May 1958) pp. 283-291. Abstr. in PDC Bi PDL-32900, p. 42.
307. Sorokin, Y. I. "Theory of chemoautotrophism." MIKROBIOLOGIYA, 25, (1956) pp. 363-375. Abstr. in CA 50:16982.

308. Sorokin, Y. I. "Utilization of carbon from CO₂ during biosynthesis by *V. desulfuricans* and some other heterotrophic bacteria," DOKLADY AKAD. NAUK SSSR, 132, (1960) pp. 464-6. Abstr. in CA 54:25027g.
309. Sorokin, Y. I. "New methods of isolation of sulfate-reducing bacteria." TRUDY INST. MIKROBIOLOGI AKAD. NAUK, SSSR, No. 2 (1952) pp. 121-9. Associated Technical Services, Inc., Translation RJ-171.
310. Spruit, C. J. F., and J. N. Wanklyn. "Iron sulfide ratios in corrosion by sulphate-reducing bacteria." NATURE, Vol. 168, No. 4283, (1951) Dec. 1, pp. 951-952. Abstr. on NACE card 5036, in CA 46:4056g, and in PDC Bi G-7956, p. 21.
311. Spurny, Milos, M. Dostalek, and J. Uehle. "A method for evaluating the sulphate-reducing bacteria." CESKOSLOV MIKROBIOL., 1: (1956) pp. 272-281. Abstr. in PDC Bi PDL-33518, p. 44.
312. Starkey, R. L. "Sulfate reduction and the anaerobic corrosion of iron." ANTONIE VAN LEEUWENHOEK, J. MICROBIOL. SEROL., 12, (1947), pp. 193-203. Abstr. in PDC Bi G-1707, p. 14.
313. Starkey, Robert L. "Susceptibility of matrix constituents of antifouling paints to microbial attack in sea water." CAN. J. MICROBIOLOGY, 3, Suppl., (Mar. 1957) pp. 231-238. Abstr. on NACE card 14376.
314. Starkey, Robert L. "Sulfate-reducing bacteria and the anaerobic corrosion of iron." Report Proc. 4th Intern. Congr. Microbiol. Abstr. in CA 44:1167. (cf CA 41:6921d; 42:5400f.
315. Starkey, R. L. "The general physiology of the sulfate-reducing bacteria in relation to corrosion." Part II. PRODUCERS MONTHLY, 22, No. 8 (1958) pp. 12. (June). Abstr. on NACE card 16632 and in PDC Bi PDL-33773, p. 44.
316. Starkey, R. L. "Transformation of iron by bacteria in water." J. OF AM. ASSOC., 37, (Oct. 1945) pp. 963-984. Abstr. in NACE Bibliography.
317. Starkey, R. L. "Symposium on autotrophy. I. Introduction." BACTERIOL. REV, 26, (1962) pp. 142-4. Abstr. in CA 58:1731f.

318. Starkey, R. L., and K. M. Wight. "Soil areas corrosive to metallic iron thru activity of anaerobic sulfate-reducing bacteria." AM. GAS. ASSOC. MONTHLY, 25, No. 5, (1943) pp. 223-8. Abstr. in CA 37:60756.
319. Starkey, R. L., and K. M. Wight. "Anaerobic corrosion of iron in soil." AM. GAS. ASSOC., TECH. REPT. DISTR. COMM., (1945) 108 pp. cf. CA 37:60756. Abstr. in CA 40:5389 and in PDC Bi G-1645, p. 13.
320. Stubbings, H. G. "Fouling and antifouling." RESEARCH, 14, (Aug. 1961) pp. 309-314. Abstr. in PDL 41659, Vol. 19, 1961, Biol. 22.
321. Stüven, Klaus. "CO and lactate assimilation in Desulfovibrio aestuarii." ARCH. MIKROBIOL., 36, No. 1 (1960) pp. 31-45. Abstr. in CA 54:21334i.
322. Stüven, K. "Physiology and classification of sulfate-reducing bacteria." ARCH. MIKROBIOL., 35, (1960) pp. 152-180. Abstr. in CA 54:21309e.
323. Sudbury, J. D. "External casing corrosion. Where is it? How bad is it?." WORLD OIL, 144, No. 6 (1957) pp. 210-222. Abstr. in CA 18560 (1957).
324. Summer, W. "Microbially induced corrosion." CORROSION TECHNOL., 7, (Sept. 1960) pp. 287-288. Abstr. in PDC Bi, p. 49.
325. Summer, W. "Microbial degradation of plastics." CORROSION TECHNOL., (April 1964). Abstr. in Corrosion Abstr., 3, (September 1964) p. 306.
326. Sussman, M. "The biology of the cellular slime molds." ANN. REV. MICROBIOL., 10, (1956) pp. 21-50. Abstr. in CA 50:16980.
327. Suzuki, Noboru. "The influence of oxygen on the development of iron bacteria." SEIRI SEITAI, 4, (1951) pp. 105-108. Abstr. in CA 48:1474b.
328. Szczepkowski, T. W., and B. Skarzynski. "The bio-chemistry of autotrophic sulfur bacteria. I. Cytochromes and hemoprotein enzymes in I. thioparus and I. thiooxidans." ACTA. MICROBIOL. POLON., 1, (1952) pp. 93-106. (cf CA 49:5581c). Abstr. in CA 50:7223f.

329. Szybalski, Wacław. "Microbiological corrosion of iron." TECH. MORZA I WYBRYEZA." Abstr. in CA 44:1389d.
330. Tada, S. "Method of testing the effect of anti-fouling paints by using artificially reared barnacle larvae." OFFICIAL DIGEST FEDERATION PAINT AND VARNISH PROD'N. CLUBS, No. 325, (1952) pp. 137-142. Abstr. on NACE card 5780.
331. Tarasov, N. I. "Marine fouling of ships and hydrotechnical constructions on the sea shores of the USSR." (in Russian with English summary) ZOOI. SHUR., 38, (Dec. 1959) pp. 1886-1997. Abstr. in PDC-38719, Vol. 18, 1961 (Fung. 68).
332. Teel, R. B., and W. F. Fair, Jr. "Testing of coal tar coatings. Part III. Resistance to fouling and degradation by marine organisms." CORROSION, 13, No. 8, (Aug. 1957) pp. 493t-500t. Abstr. on NACE card 14103.
333. Tehle, E. Jr. "The bacteriostatic activity of 2-alkyl-tetrahydropyrimidines and derivatives against Desulf. vibrio desulfuricans, mid-continent strain A, Texas, Co." PRODUCER'S MONTHLY, 24, No. 6 (1960) pp. 26-27. Abstr. in CA 54:1866c.
334. Temple, K., and A. R. Colmer. "The autotrophic oxidation of iron by a new bacterium; Thiobacillus ferrooxidans." J. BACT., 62, (Nov. 1951) pp. 605-611. Abstr. in PDC Bi G-7499, p. 21.
335. Thayer, S. "Effect of barnacles and corrosion of metals and alloys suspended in sea water." CORROSION, 6, No. 9, (Sept. 1950) New Section, p-1. Abstr. in NACE Bibliography.
336. Thompson, P. F. "Corrosion of condenser tubes. Part 3. Effects of biological factors and crystals structure, with concluding remarks." Australia council for scientific and industrial research. Div. of Aeronautics. Report SM. 113; Australia Scientific Liaison Office, Washington. Australian Tech. Papers No. 1666 (June 1948) 31p. Abstr. in PDC Bi B-403(3), p. 2.
337. Tiller, A. K., and G. H. Booth. "Polarization studies of mild steel in cultures of sulfate-reducing bacteria. II. Thermophilic organisms." TRANS. FARADAY SOC., 58, (1962) p. 110-115. cf CA 55:13538d. Abstr. in CA 57:833b and in PDC Bi PDL-44482, p. 65.
338. Trautenberg, G. A. "Sulfate reduction in bacterial corrosion." MATERIALS PROTECTION, 3, No. 2, (Feb. 1964), pp. 30-34. Abstr. in Corrosion Abstr., 3, (March 1964) p. 82.

339. Tyler, M. E., M. C. Bielling, and D. B. Pratt. "Mineral requirements and other characters of selected marine bacteria." J. GEM. MICROBIOL., 23, (1960) pp. 153-61. Abstr. in CA 54:25042f.
340. Uhlig, Herbert H., Editor. "Action of anaerobic bacteria." CORROSION AND CORROSION CONTROL. John Wiley and Sons, Inc. New York. pp. 83-84.
341. Uhlig, Herbert H., Editor. "Factors affecting corrosivity of soils." CORROSION AND CORROSION CONTROL. John Wiley and Sons, Inc. New York. pp. 150-151.
342. Ulanovskii, I. B., and Nikitina. "Influence of putrifying aerobes on corrosion of steel in sea water." MIKROBIOLOGIYA, Vol. 25, (1956) pp. 66-71. Abstr. in CA 50:11916i and in PDC Bi PDL-30150, p. 39.
343. Ulanovskii, I. B., L. A. Rozenberg, and Y. M. Korovin. "The effect of bacteria upon the electrode potentials of stainless steels in sea water." MIKROBIOLOGIYA, Vol. 29 (1960) pp. 281-286. Abstr. in PDC Bi PDL-38415, p. 51.
344. Ulanovskii, I. W., N. I. Tarasov, E. P. Turpaeva, and Y. M. Korovin. "Corrosion of stainless steel resulting from the metabolic activity of barnacles." NAUK SSSR, Vol. 132, (June 1960) pp. 941-944. Abstr. in PDL-39722. Vol. 18, (1961).
345. Ulanovskii, I. B., N. I. Tarasov, and Y. M. Korovin. "The effect of sea-acorns on the corrosion of stainless steels." NAUK SSSR, Vol. 125 (1959) pp. 1137-1140. Abstr. in PDL-36120, (1960) Vol. 18.
346. Umbreit, W. S. "Symposium on autotrophy. II. The comparative physiology of autotrophic bacteria." BACTERIOL. REV., 26, pp. 145-50. Abstr. in CA 58:1731f.
347. United States Naval Institute, Annapolis, Maryland. "Marine fouling and its prevention." 400 pp. (1952) Abstr. on NACE card 4500.
348. Updegraff, David M. "Microbiological corrosion of iron and steel." CORROSION, Vol. 11, No. 10 (October 1955) pp. 442t-446t. Abstr. on NACE card 9756a.

349. Valentine, R. C., and R. S. Wolfe. "Role of ferredoxin in the metabolism of molecular hydrogen." *J. BACTERIOL.*, 85, (1963) pp. 1114-20. Abstr. in CA 56:12880c.
350. Vernon, L. P., J. H. Mangum, J. V. Beck, and F. M. Shafia. "A ferrous-ion oxidizing bacterium. II. Cytochrome composition." *ARCH. BIOCHEM. BIOPHYS.*, 88, No. 2, (1960) pp. 227-31. Abstr. in CA 54:21316b.
351. Vernon, W. H. J. "Principles of corrosion. Part 2. Why metals corrode?" *CORROSION PREVENTION AND CONTROL*, 1, 639, pp. 591-600. (Dec. 1954). Abstr. in PDC Bi G-10588, p. 32.
352. Vernon, W. H. J. "The corrosion of metals." *ROY. SOC. ARTS J.*, 97, (July 1949) pp. 578-610. Abstr. in PDC Bi G-5000, p. 19.
353. Vernon, W. H. J. "Recent progress in the investigation on corrosion and microbiologic corrosion." *METAUX ET CORROSION*, Vol. 23, (1948) pp. 34-40. Abstr. from CA 43:1706d.
354. Vernon, W. H. J. "Metallic corrosion." *RESEARCH (London)* 5, (1952) pp. 54-61. Abstr. in CA 46:4456e.
355. Vishniac, W., and P. A. Trudinger. "Symposium on autotrophy V. carbon dioxide fixation and substrate oxidation in the chemo-synthetic sulfur and hydrogen bacteria." *BACTERIOL. REV.*, 26, pp. 168-175. Abstr. in CA 58:1731f.
356. Wachs, A. M., S. Bentur, Y. Kott, M. Babitz, and A. B. Stern. "Aviation gasoline corrosiveness caused by sulfate-reducing bacteria. Prevention by growth inhibitors." *IND. AND ENG. CHEM., PROCESS DESIGN DEVELOP.*, 3, (1964) pp. 65-69. Abstr. in *Corrosion Abstr.*, 3, (July 1964) p. 222.
357. Ward, C. B. "Corrosion resulting from microbial fuel tank contamination." *MATERIALS PROTECTION*, 2, (June 1963) pp. 10-12, 14-16. Abstr. in PDC Bi PDL-48221, p. 70.
358. Watkins, F. M. "Microorganisms affect oil." (Dec. 1960) 10 pages (Sinclair Research Laboratories, Inc., Harvey, Ill.) Abstr. in PDC 1961-Vol. 19, Biol. 1, PDL 40608.
359. Williams, Trevor J. "The battle against corrosion." *AUSTRALASIAN ENG.* (May 7, 1951) p. 149. Abstr. in NACE Bibliography.

360. Wilson, O. B. "Anaerobic corrosion of buried iron pipes." JOURNAL OF THE AM. WATER WORKS ASSOC., 38, (Oct. 1946) pp. 1212-1213. Abstr. in PDC Bi G-552, p. 8.
361. Wise, R. S. "Significance of slime in causing corrosion and mechanisms of corrosion by slime growth." AMER. SOC. OF MECHANICAL ENGINEERS, New York, N. Y. Paper No. 55-S-40. Abstr. in PDC Bi G-11791, p. 35.
362. Wolfson, L. L. "Microbiology in secondary recovery systems." CORROSION, Vol. 16, No. 6, (June 1960) pp. 298t-300t. Abstr. on NACE card 19601.
363. Woods, D. D. "Integration of research on the nutrition and metabolism of microorganisms." J. GEN. MICROBIOL., 9, (1953) pp. 151-173. Abstr. in CA 48:1476g.
364. Wood, E. J. F. "Marine bacteria in relation to economic processes." AUSTRALIAN J. SCI., 16, (Dec. 1953) pp. 87-91. Abstr. in PDC Bi G-9752, p. 30.
365. Wood, E. J. F. "Marine bacteria in relation to economic processes." Intern. Congr. Microbiol., Rept. Proc. 6th Cong., 3, (Sept. 1953) pp. 3280329. Abstr. in PDC Bi PDL-30292, p. 39.
366. Wormwell, F., and T. W. Farrar. "Electrochemical studies of anaerobic corrosion in presence of sulfate-reducing bacteria." CHEMISTRY AND INDUSTRY (1952) pp. 108-109. Abstr. in CA 46:4455h.
367. Woratz, H., E. Thofern, and A. Kariminejad. "The effect of copper sulfate on the enzymic activity of resistant bacteria." ZENTR. BAKTERIOL PARASITENK. ABT. I. Orig., 168, (1957) pp. 436-440. Abstr. in CA 51:16702h.
368. Wright, C. C. "What we're learning about bacterial corrosion." OIL GAS. J., 60, No. 26 (1962) pp. 124-125. Abstr. in CA 57:10108e.
369. Wright, R. H., and H. F. Hostetler. "Microbiological diesel fuel contamination." SAE Paper 651B-Presented at the Automotive Engineering Congress, Detroit, Mich., (Jan. 14-18, 1963). Abstr. in PDL Abstract 84113.
370. Yagi, T., and N. Tamiya. "Enzymic oxidation of carbon monoxide." III. Reversibility." BIOCHIM. BIOPHYS. ACTA., 65, (1962 (in Engl.) of CA 52:20236a. Abstr. in CA 58:7154b.

371. Yagi, T., and M. Tamiya. "Enzymic oxidation of carbon monoxide." KOSU KAGAKU SHIMPOJIMU, 15, (1961) pp. 73-76. Abstr. in CA 55:24857a.
372. Yagi, T. "Enzymic oxidation of carbon monoxide." BIOCHIM. ET BIOPHYS. ACTA., 30, (1958) pp. 194-195. Abstr. in CA 53:3329f. Part II Abstr. in 53:20236a.
373. Yamada, K., J. Takahashi, and K. Kobayashi. "The utilization of hydrocarbons by microorganisms." AGR. BIOL. CHEM. (TOKYO), 26, (Sept. 1962) p. 636. Abstr. in PDL-48085.
374. Zador, S. "Effect of temperature on the oxidation-reduction potential in bacterial cultures." ACTA BIOL. ACAD. SCI. HUNG., 11, (1962) pp. 3870392. (in English). Abstr. in CA 55:26105c.
375. ZoBell, C. E. "Marine microbiology." ASTIA Doc. 82569 (Jan. 1956) 13 p. Abstr. in PDC Bi G-13045, p. 37.
376. ZoBell, C. E. "Marine bacteriology." ANN. REV. BIOCHEM., 16, (1947) pp. 565-586. Abstr. in CA 41:6923d.
377. ZoBell, C. E. "Ecology of sulfate-reducing bacteria." Reprint from May 1958 issue of Producers Monthly, Vol. 22, No. 7, pp. 12-29.
378. ZoBell, C. E. "Microbiol transformation of molecular hydrogen in marine sediments, with particular reference to petroleum." BULL. AM. ASSOC. PETROLEUM GEOL., 31, (1947) pp. 1709-1751. cf CA 40:38³. Abstr. in CA 42:1158g.
379. ZoBell, C. E. "Studies on redox potential of marine sediments." BULL. AM. ASSOC. PET. GEOL., 30, No. 4, (April 1946) pp. 477-513.
380. ZoBell, C. E., and R. Y. Morita. "Marine microbiology." ASTIA Doc. 69969 (July 1955) 22 p. Abstr. in PDC Bi G-12611, p. 37.
381. ZoBell, C. E., and R. Y. Morita. "Effects of high hydrostatic pressure on physiological activities of marine microorganisms." Scripps Inst. of Oceanography, La Jolla, Calif. Ref. 55-2; Its Semi-Annual Progress Report No. 8; U. S. Office of Naval Research Contract Nonr-275 (Dec. 1964). ASTIA Doc. 55005. Abstr. in PDC Bi G-11475.
382. ZoBell, C. E., and Sydney C. Rittenburg. "Sulfate-reducing bacteria in marine sediments." J. MARINE RESEARCH (Sears Foundation), 7, (1948) pp. 602-617. Abstr. in CA 43:5076.

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