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Microbiology Corrosion Metabolism in Oil Field

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Abstract

Corrosion of metals frequently occurs in various settings, leading to the degradation of engineered materials. This phenomenon often causes financial losses and poses risks to personal safety. Due to the abundance of microbial species and the increasingly complex and demanding environments in which metallic materials are used, microbial corrosion is closely linked to both the environment and the microbial species, which as a result, microbial corrosion faces numerous challenges. In addition, the process of microbial corrosion is incredibly complicated thus requires additional research. One of the primary causes of biocorrosion, which destroys oil facilities such as storage tanks, pipelines, separators and wells, is bacteria. Because iron- and sulfate-reducing bacteria can be resistant to a wide range of chemicals, several companies and researchers are working to develop a new way to eradicate the microorganisms. This paper discusses the metabolism of corroded metals by iron and sulfate-reducing bacteria. It also discusses methods for monitoring sulfate-reducing bacteria in a system, including laboratory identification and enumeration procedures. Finally, some biocide considerations are presented.

Keywords: Sulfate Reducing Bacteria (SRB), Iron Bacteria, Slime Forming Bacteria, Nitrate Reducing Bacteria, Corrosion, Biocide, Chlorination.

1. INTRODUCTION

The field of microbiology, a branch of biology, is related to the study of minute living organisms, collectively known as microbes (Figure 1). The behaviour of single-celled, microscopic plants, which are capable of surviving in a variety of environments and proliferating at an astonishing rate, represents our primary area of interest. Biology involves exploring the fundamental functions of living entities, broadly examining how plants and animals exist and interact(Khalid et al., 2023, Green and Goldman, 2021).

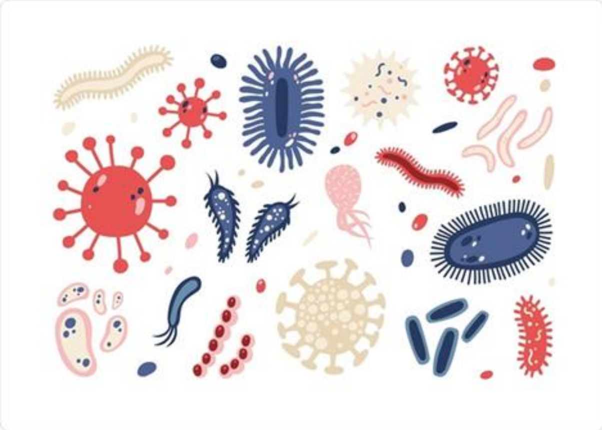


Figure 1: illustrates some examples of microorganisms.

The lowest part of the plant is made up of microbes. The three primary categories of microorganisms are bacteria, fungi, and algae. If properly protected by scale or debris, bacteria—a diverse class of microorganisms that live in colonies or groups—are extremely difficult to eradicate(Pitt and Barer, 2012).

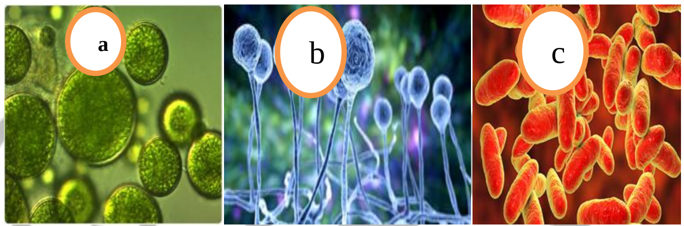


Figure 2: (a) Algae, (b) Fungi, (c) Bacteria

A beneficial manner to categorize microorganism in oilfield structures is with the aid of determining if a given bacterium needs oxygen to survive. There are three varieties of them:
First, aerobic bacteria, which want oxygen to develop. second, anaerobic microorganism thrive when oxygen is not present. The third sort of microorganism are facultative; they could grow with or without oxygen. (Parker et al., 2021, Nielsen et al., 2021). Bacteria can multiply at an amazing rate, which is why they can cause us so much trouble. A single bacterium can grow into a thriving colony of millions of bacteria in a matter of hours under many circumstances, as they can double in number in 20 minutes. More bacteria can be found in a handful of water slime than there are people on the planet (Maier and Pepper, 2015, La Rosa et al., 2014). Bacteria, for instance, can grow in a very broad range of environments, but they prefer the pH range of 5 to 9 and the temperature range of 0 to 180 ^{o}C (Pitt and Barer, 2012).
There are thousands of species of bacteria, which are minuscule organisms with a diameter of only a few inches. Spherical, straight, or curved rod shapes are characteristics of true bacteria. The shapes are called as follows in microbiologist terminology: I) A single spherical bacterium is called a coccus, and several spherical bacteria are called cocci. It is interesting to note that a

sheet or plane of cocci is identified as a staphylococcus, while a string of cocci chains is classified as a streptococcus. II) A bacillus is shown as a straight rod. III) A spiral spirochete is a curved rod(see Figure 3).(Yang et al., 2016).

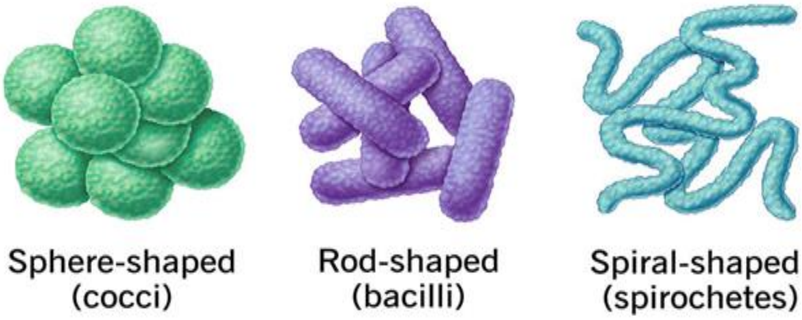


Figure 3: Shapes of bacteria

2. Corrosion Caused By Microbes

Microbial corrosion is a unique type of electrochemical corrosion. Microalgae, fungi, bacteria, and archaea are the most prevalent corrosive microorganisms that cause metallic corrosion (Little et al., 2020, Puentes-Cala et al., 2022, Al-abbasi et al., 2022). The release of exogenous enzymes and metabolites brought on by microbial cell metabolism may be the cause of physical failure (Maji and Lavanya, 2024). Microbial corrosion refers to the deterioration of materials, both metallic and non-metallic, caused by microbial activity within biofilms attached to their surfaces(Maji and Lavanya, 2024). Fuel tanks and any other metal parts that come into contact with soil, water, or moist air have been shown to be vulnerable to microbial corrosion. Electric power and other industrial cooling water systems, underground pipelines for gas, water, and oil, cables, oil wells, water injection wells in oil production systems, gas storage tanks, and oil tanks are all included in this (Xu et al., 2024, Knisz et al., 2023, Al-abbasi, 2021, Sida, 2024). Numerous industries, including but not limited to production capacity, chemical reactions, the oil and gas sector, shipyards, and the military, are significantly impacted by the process. Microbial corrosion has substantial financial costs; according to statistics, microbiological corrosion accounts for 20% of corrosion damage to metals and building materials (Fayomi et al., 2019). According to estimates, microbial corrosion—which is mainly linked to the sulfate reduction process—is to blame for over 75% of corrosion in oil wells and roughly 50% of underground pipeline and cable failures(Telegdi et al., 2017a).

Not until 1910 was it realized that microbes were the cause of metallic corrosion (2008, Lavanya, 2021). According to Pal and M N (2022), the migration, attachment, and subsequent growth of microorganisms on a metal surface is known as microbiological corrosion. Alongside this process, metabolites, corrosion products, certain inorganic minerals, and organic matter continuously accumulate in the surrounding environment, forming a biofilm (Lavanya, 2021).

3. Corrosive Microbes

3.1 Bacteria

Oilfield systems suffer greatly from bacteria, which can lead to a variety of issues such as formation face damage, iron sulfide scaling, hydrogen sulfide generation, emulsification, and corrosion influenced by microbes (Penkala et al., 2004, Al-Abbassi et al., 2023, Khalifa, 2018). Sulfate-reducing and iron-oxidizing bacteria are the two most common classifications for corrosive bacteria (Telegdi et al., 2017a, Pitt and Barer, 2012).

3.1.1 Sulfate Reducing Bacteria

Sulfate-reducing bacteria usually use organic carbon sources as electron donors and are extremely corrosive to metals. However, they can use iron as an electron donor to help sulfate reduction in situations where organic carbon sources are limited (TIAN Yuan, 2020, Bagheri Novair et al., 2024). Sulfate-reducing bacteria can use sulfate as a terminal electron acceptor rather than oxygen to oxidize intermediate metabolites for energy in anaerobic environments. As a result, bacteria that reduce sulfate are categorized as anaerobic (Figure 4).

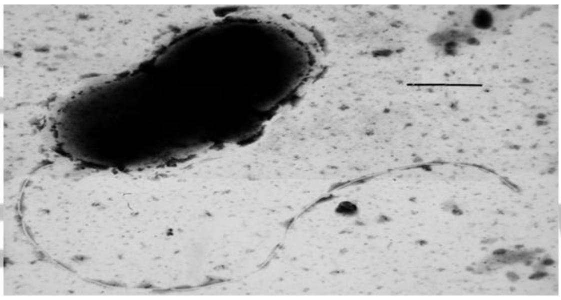


Figure 4: Sulfate-reducing bacteria under a microscope

Since their metabolism can lead to corrosion, sulfate-reducing bacteria most likely cause more significant issues in oilfield plants than other bacteria (Shi et al., 2023). Sulfate-reducing bacteria convert waterborne sulfate ions into sulfide ions, producing H_2S as a by-product. This compound, highly soluble in water, forms an acidic solution that drastically speeds up metal corrosion(Abdalsamed et al., 2020).

3.1.2 Iron Bacteria

One typical aerobic corrosive microbe that falls under the category of metal deposition microorganisms is iron-oxidizing bacteria. The oxidation of Fe^{2+} to Fe^{3+}, which speeds up the metal's corrosion, provides the majority of the energy needed for its growth (TIAN Yuan, 2020). The biocatalytic activity of the iron-oxidizing bacteria caused a decrease in the concentration of Fe^{2+}, which in turn accelerated the dissolution of Fe by encouraging the loss of electrons (TIAN Yuan, 2020). Near neutral conditions generate a significant amount of the corrosion product $Fe(OH)_3$. There are many anodic areas that form on steel surfaces when $Fe(OH)_3$ is present (TIAN Yuan, 2020).

Figure (5): Pipes corroded by iron bacteria

As iron bacteria grow, they surround themselves with an iron hydroxide sheath. Although they are categorized as aerobic bacteria, iron bacteria include Gallionella, which can thrive with very little oxygen (Emerson et al., 1999, TIAN Yuan, 2020).

Iron bacteria are capable of causing plugging as well as corrosion. Sulfate reducers operating beneath the hydroxide sheath or the formation of an oxygen concentration cell can both cause corrosion, even though they are not directly involved in the corrosion reaction (Emerson et al., 1999, TIAN Yuan, 2020). Significant plugging issues can result from the precipitation of enough ferric hydroxide by a large number of iron bacteria (Figure 7) (Beimeng et al., 2016).

3.1.3 Slime Formers

A broad class of aerobic bacteria known as slime-forming bacteria is able to form dense masses of slime on solid surfaces. Pseudomonas, Aerobacter, Flavobacterium, Escherichia, and Bacillus are a few examples. They are excellent pluggers and, by protecting a portion of the surface, they cause corrosion in the same ways as iron bacteria. Both freshwater and brine systems are susceptible to slime (Telegdi et al., 2017b).

3.1.4 Nitrate Reducing Bacteria

Nitrate reducing bacteria (NRB) can acquire electrons by reducing nitrate in an oxygen-free environment. These bacteria function on a reduction basis. Although the biofilm produced by nitrate-reducing bacteria corrodes metal surfaces, it is thought to be less harmful than sulfate-reducing bacteria (Liu et al., 2021).

3.2 Algae

In open freshwater systems that store water in pits or open tanks, algae growth may be an issue. Sunlight is essential for the growth of algae. Additionally, brine growth is not a major issue. Algae can be drawn into a system and cause plugging because they grow on the water's surface. Anaerobic conditions conducive to the growth of sulfate reducers may arise in the water if they completely cover a pit or pond (Singh and Singh, 2015). The group of organisms known as algae are found all over the planet, have a high level of ecological adaptation, and reproduce readily (TIAN Yuan, 2020, Shalaby, 2011). They can be divided into three groups based on their structure, color, and biological traits: red, green, and brown algae (TIAN Yuan, 2020, Yoon et al., 2006). Red algae can be found in freshwater habitats, but they are mostly found in the ocean. The majority of bacteria and microalgae interact to seriously corrode and contaminate metallic materials. The presence of biofilms facilitates the growth of diatom cells and algae spores (TIAN Yuan, 2020, Mieszkin et al., 2013). Additionally, some bacteria produce organic carbon-based metabolites and profit from the oxygen generated by algal photosynthesis (TIAN Yuan, 2020, Selvarajan et al., 2019), whereas other epiphytic bacteria stop algae from sticking to metal surfaces. The biofilm of Shewanella algae, for instance, speeds up the corrosive process of 316L stainless steel. Algae not only cause extreme biofouling but also accelerate metal corrosion (TIAN Yuan, 2020, Kalnaowakul et al., 2020).

3.3 Fungi

A diverse group of organisms that are constantly present in environments are fungi. It is stated by Juzeliūnas et al (Juzeliūnas et al., 2007). According to Juzeliūnas et al. Aspergillus niger can either accelerate or inhibit zinc and aluminum corrosion, depending on the metal it colonizes, according to research on the fungus's impact on these metals (TIAN Yuan, 2020). According to Dai et al., Aspergillus niger's oxalic acid secretion accelerated the corrosion of 2024 aluminum alloy (Dai et al., 2016). Metal corrosion is caused by organic acids produced by Aspergillus niger (TIAN Yuan, 2020). Non-anodized 6061 aluminum alloys exhibit more severe uniform and localized corrosion than anodized 6061 aluminum alloys, depending on the length of time the fungus grows (TIAN Yuan, 2020, Jirón-Lazos et al., 2018).

3.4 The Archaea

One important component of the microbial community is archaea (TIAN Yuan, 2020). Despite being found all over the planet, archaea are primarily found in harsh environments like deep oceans that are completely anaerobic and acidic or alkaline soils (TIAN Yuan, 2020, Woese et al., 1990). Archaea dominate in these conditions, while regular bacteria find it difficult to survive. There are numerous archaeal types that can be categorized based on their living conditions, including methanogenic, thermophilic, halophilic, acidophilic, and ammonia-oxidizing archaea (Leininger et al., 2006).

Methanogenic archaea are anaerobic, chemoautotrophic, or chemoheterotrophic archaea that produce methane. Typically, they can be found in anoxic environments like hot springs, submerged hydrothermal vents, anaerobic wastewater treatment facilities, marshes, and marine sediments. As stated by Chen and colleagues (Chen et al., 2022), methanogenic archaea employed H^+ as an electron acceptor, which facilitated the anodic and cathodic charge transfer process and hastened the corrosion of E690 steel in seawater (TIAN Yuan, 2020).

In accordance with the research conducted by Qian et al. , 2020 (Qian et al., 2020), the passivation layer on 304 stainless steel had higher Fe^{2+} and Cr^{6+} contents due to the salinophilic erythrophilic bacterium (Natronorubrum tibetense) (TIAN Yuan, 2020). Thermophilic archaea that come into direct contact with metal surfaces cause cathodic depolarization and direct electron transfer, which oxidizes Fe^0 to Fe^{2+} and causes steel materials to corrode (TIAN Yuan, 2020, Suarez et al., 2019).

4. Culturing, Identifying and Counting Bacteria

Sampling, identifying, and counting the bacteria is part of keeping an eye on a system for bacterial activity. A microbiologist can use a microscope to identify iron, slime bacteria, and algae through microscopic examination, but this method is not effective in oil fields. But the goal of culturing bacteria is to make them grow; this is similar to culturing green beans, potatoes, or flowers.

4.1 A Culture Medium

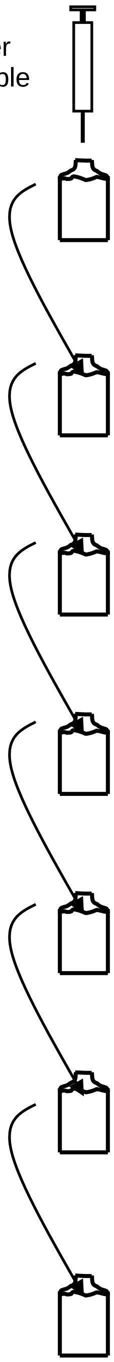
A culture medium, which is essentially a solution containing food that will encourage the growth and multiplication of the bacteria of interest, is added to a water sample that is suspected of containing bacteria. Different culture media are needed for different kinds of bacteria, and some bacteria won't grow at all in artificial media. Thankfully, a specific medium can be used to cultivate the majority of bacteria of interest. It is feasible to identify the bacteria by merely noting the media in which growth took place because media can be created that will only allow for the growth of particular types of bacteria. Additionally, the number of each type of bacteria can be estimated by running the sample at multiple dilutions (Bonnet et al., 2020).

4.2 Extinction Dilution Technique

Laboratory Methods: This article will not discuss the various variations of laboratory identification and counting methods (Váradi et al., 2017). A petri dish is frequently used in laboratories to identify bacteria (Wildan et al., 2020). Water samples can be cultured in the field using a process called the extinction dilution technique, which makes use of the methods and media mentioned. Here is how the process is carried out: I) A number of serum bottles holding nine milliliters of sterile growth medium were lined up. II) The first bottle was filled with 1 mL of the water sample and thoroughly shaken. III) Using a disposable sterile syringe, one milliliter of solution was taken out of the first bottle and injected into the second. The bottle was then thoroughly shaken, and the syringe was disposed of. VI) A fresh sterile syringe was used to remove 1 mL of solution from the second bottle and inject it into the third bottle. The bottle was then thoroughly shaken, and the syringe was disposed of.

This process, called serial dilution, can be carried out for as many bottles as you like. The extinction dilution technique gets its name from the fact that the goal of this process is to dilute the sample until there are no bacteria left in the last 1 mL of solution that is injected into the bottle. Any bacteria in the sample will be exterminated because you have diluted it so much. The bacterial population of the initial 1 mL water sample can be estimated thanks to the series of dilutions that are carried out. Nine milliliters of growth medium are included in each bottle (Shen and Voordouw, 2017).

Extinction Dilution Technique Diagram



1 ml. Water Sample	**Bottle No.**	**Dilution Factor**	**Number of Bacteria in Original 1 ml. Water Sample**
1 ml	1	0	1 colonies Bacteria / ml
1 ml	2	1:10	10 colonies Bacteria / ml
1 ml	3	1:100	100 colonies Bacteria / ml
1 ml	4	1:1000	1000 colonies Bacteria / ml
1 ml	5	1:10,0000	10,000 colonies Bacteria / ml
1 ml	6	1:100,000	100,000 colonies Bacteria / ml
1 ml	7	1:1,000,000	1,000,000 colonies Bacteria / ml

Two different series of dilutions are conducted in the investigation using two different types of culture media. Bottles containing a general bacterial growth medium are used in the first series. In the second series, bottles containing a distinct growth medium tailored to sulfate-reducing bacteria are used. The slime formers and other general aerobic bacteria are included in the general count. Iron bacteria are not included because they can only be found by microscopic means and cannot be cultivated in an artificial medium. After sampling, the water sample should ideally be injected right into the growth medium. Bacterial populations fluctuate rapidly, and outdated samples may provide an inaccurate representation of the water system's population. First, samples should not be cultured for longer than an hour following sampling, according to recommended practices. Second, check to see if H_2S reacts with the medium using an empty bottle if it is present. Check the levels of H_2S using the hydrogen sulfide test kit.

4.3 Interpretation of Results

The best way to interpret the results is to use an example: if bottle 1 gets cloudy but the other bottles stay clear, then there is about one colony of bacteria per milliliter in the water. About 100 bacterial colonies per milliliter are present in the water if bottles 1, 2, and 3 start to cloud but the other bottles stay clear. If bottle 1 turns black but the other bottles stay clear, then the water contains about one colony of sulfate-reducing bacteria per milliliter. The water contains about 100 colonies of bacteria per milliliter if bottles 1, 2, and 3 turn black but the other bottles stay clear. A count of 100,000 per milliliter suggested that plugging was likely to occur and that biocide treatment was required.

Following inoculation, the bottles are placed aside and given 30 days to "incubate.". Growth rates are sensitive to temperature, so it is ideal to maintain a consistent temperature throughout the incubation period. In the field, this means letting them grow at room temperature at home or leaving them in the office. Check them every day for indications of growth. If the serum bottle turns black (for sulfate reducers) or turbid or cloudy (for general bacteria), growth is indicated. Generally speaking, bacterial growth takes three days, but sulfate reducer growth may take two weeks to a month. After seven days, the last reading for general bacteria should be obtained. After a month, the sulfate reducers should be counted one last time.

4.4 Water Sampling Collection for Bacterial Analysis

The following sampling locations should be used in an injection system: the wellhead and produced water can be used as a water source. Samples should be collected from the inlet and the outlet of tanks, filters, and vessels. Samples for injection wells should be collected from multiple injection wellheads that are situated at different separations from the injection plant. As a result, the required growth media must be obtained in sterilized bottles with screw-on caps. If assistance is required to culture scale samples, one should contact a chemical company or consulting laboratory. If the system exhibits any indication of bacterial activity, it is strongly advised.

5. Mechanism of Bacterial Corrosion

5.1 Sulfate Reducing Bacteria

Bacteria that reduce sulfate are the most detrimental microorganisms in anaerobic microbial corrosion. They transform sulfate into sulfide, fostering the growth of a sulfide coating. The most frequently encountered highly corrosive bacteria in oil fields are identified as Disulfovibrio, which operate entirely in an oxygen-free environment. The production of sulfur by bacteria brings about severe implications for pitting corrosion, as depicted in (Figure 6).

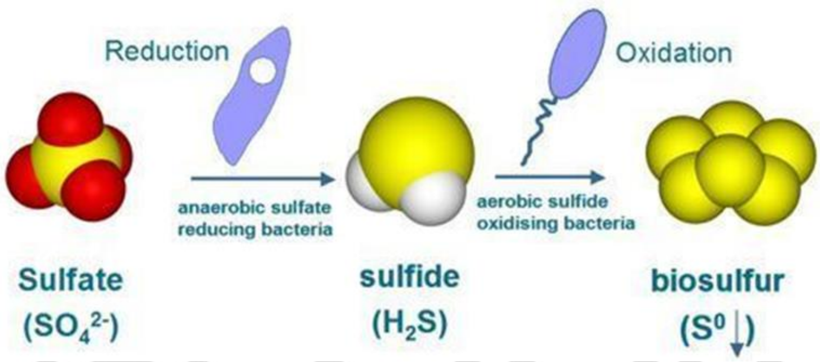


Figure 6: Sulfur formation by sulfate-reducing bacteria (Manafi et al., 2013)

Mechanism of corrosion Like anaerobic bacteria, corrosion stops when cathodic depolarization is absent. The mechanisms that propel continuous corrosion are catalyzed in this manner by biological enzymes (Figure 7a and 7b). The following describes the cathodic depolarization process.:

$$4Fe \rightarrow 4Fe^{2+} + 8e \text{ (cathodic process)}$$

$$8H_2O \rightarrow 8H^+ + 8OH^- \text{ (water ionization)}$$

$$8H^+ + 8e \rightarrow 8H \text{ (cathodic process)}$$

$$SO_4^{2-} + 8H \rightarrow S^{2-} + 4H_2O \text{ (cathodic depolarization of bacteria)}$$

$$Fe^{2+} + S^{2-} \rightarrow FeS \text{ (corrosion product)}$$

$$3Fe^{2+} + 6OH^- \rightarrow 3Fe(OH)_2 \text{ (corrosion product)}$$

The complete reaction formula:

$$4Fe + SO_4^{2-} + 4H_2O \rightarrow 3Fe(OH)_2 + FeS + 2OH^-$$

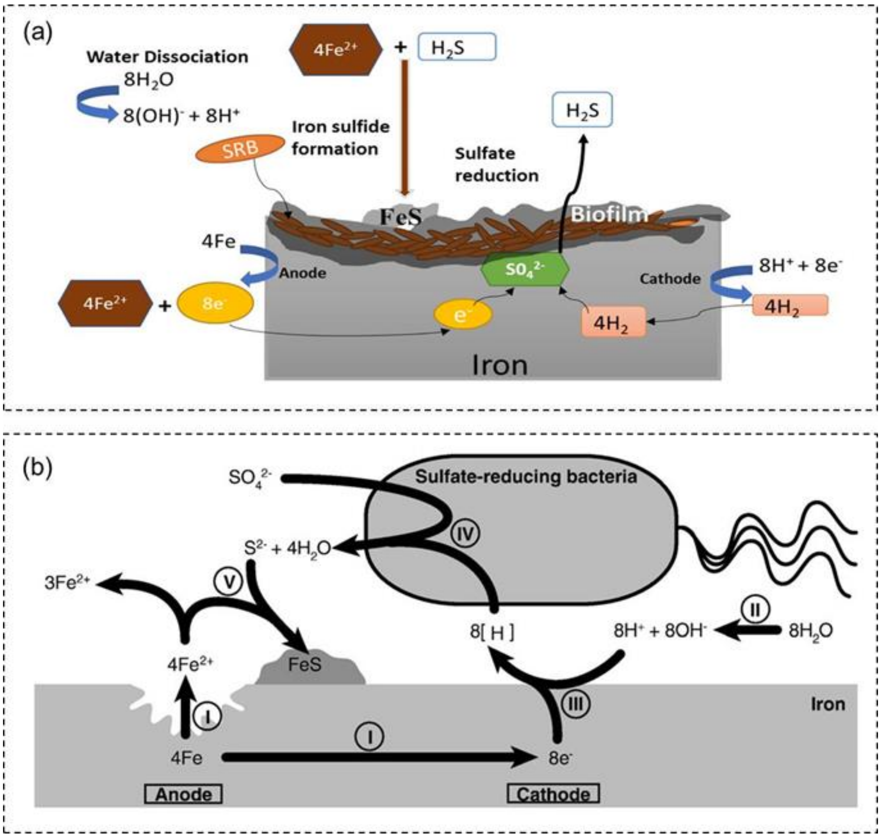


Figure 7: Metabolism of sulfate-reducing bacteria biofilm formation(Tripathi et al., 2021, Abdalsamed et al., 2020)

Bacteria that reduce sulfate are a warning sign. Iron sulfide, which is a byproduct of the corrosion reaction, is a great plugging material, but using too many sulphate reducers is bad and biocide treatment should be started (Enning and Garrelfs, 2014). (Enning and Garrelfs, 2014).

5.2 Iron Bacteria

Iron bacteria are inextricably linked to oxygen because of their aerobic nature. The majority of iron hydroxide precipitates, which are created by iron bacteria, produce energy by oxidizing iron ions to Fe^{3+} ions. By oxidizing ferrous ions to Fe^{3+} ions, iron bacteria produce iron hydroxide precipitates, most of which turn into $Fe(OH)_3$ precipitates. Numerous types of iron bacteria aid in the precipitation of oxidized iron ions. According to studies, rust scale, which quickly precipitates a sizable amount of iron oxide, is primarily caused by iron bacteria. The biological rate of iron oxidation is significantly higher than the abiotic rate. Iron-oxidizing bacteria work in regions with high oxygen concentrations through the mechanism of crevice corrosion, splitting the metal surface into small anodic patches and wide cathodic zones (under dense iron hydroxides and products). The following occurs when iron bacteria grow an oxygen-concentrating cell on a water pipe's inner wall.

$$2Fe \rightarrow 2Fe^{2+} + 4e \text{ (anodic process)}$$

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \text{ (cathodic process)}$$

$$2Fe^{2+} + 4OH^- \rightarrow 2Fe(OH)_2 \text{ (corrosion product)}$$

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 2Fe(OH)_3 \text{ (corrosion product)}$$

$$\text{Total reaction formula } 4Fe + 6H_2O + 3O_2 \rightarrow 2Fe(OH)_3$$

6. Microbial Corrosion Protection

Microbial corrosion is difficult to eradicate due to the diversity and complexity of bacteria. Since completely preventing microbial corrosion remains challenging, multiple strategies are employed, such as using spores, capping methods, electrochemical protection, and biological controls. Coatings, preservatives, fungicides, corrosion inhibitors, strippers, preservatives, or cleaners are typically used in combination to optimize corrosion control in closed or semi-closed systems. The following categories apply to the types of chemicals used to control bacteria:

a) Bactericide: A chemical that destroys bacteria.

b) bacteriostat is a substance that stops or slows down the growth of bacteria.

c) Biocide: A substance that, in addition to bacteria, destroys other living things.

d) Biostat: A substance that prevents or slows the development of other living things (Abdalsamed et al., 2020).

6.1Type of Biocide

6.1.1 Inorganic Chemicals

The most popular inorganic biocide for water injection systems is chlorine. Although they have bactericidal properties, chromates and silver and mercury compounds are rarely utilized in injection systems (Okoro, 2014).

6.1.2 Organic Composition

Common examples of organic bactericides include quaternary ammonium compounds, amines, and chlorinated phenols. Except for chlorine, the majority of bactericides marketed by chemical companies are organic (Jones and Joshi, 2021).

6.1.3 Chlorination

Since chlorine is one of the most affordable and efficient bactericides, it is used extensively. Chlorine reacts with a variety of materials because it is a potent oxidizing agent. It can no longer kill bacteria once it has reacted. Therefore, in order to determine the total amount of chlorine required, it is necessary to determine how much chlorine will be consumed by reaction with other materials.

Time, temperature, and pH all affect how much chlorine is needed to achieve a kill. According to Ghernaout (2017) and Cheswick et al., the rate of kill rises with temperature and falls with pH. (Ghernaout, 2017, Cheswick et al., 2020, Yang et al., 2018). Sulfite ions, hydrogen sulfide, ferrous iron, and organic compounds (corrosion inhibitors and scale control chemicals) are among the substances that chlorine will react with. Other techniques for eliminating bacteria include ozone, hydrogen peroxide, X-rays, and UV radiation, but these are typically applied to portable water (Vanhaelewyn et al., 2020).

6.2 Biocide Selection and Evaluation

The selection of a chemical to control corrosion or scale is comparable to the selection of a biocide for bacterial control. It is necessary to first determine the type of bacterial issue before selecting a chemical that will effectively address it. The first step in choosing a chemical is to evaluate various bactericides in a laboratory.

6.3 Several Items must be Considered in the Selection

a) Kill or Control: Depending on the kind of bacteria present, either a bactericide or a bacteriostat should be used. Because a complete kill is desired, sulfate reducers need a biocide. A bacteriostat is frequently used to control slime formers because a respectable number of them can be tolerated without causing major issues.

b) Resistant Strains: It is a very discouraging habit of bacteria to evolve strains that gradually become resistant to a specific chemical. Even if you are consistently adding a bactericide to the system, they may still continue to grow and cause issues. As a result, choosing at least two bactericides and applying them alternately is a good idea. The issue will then be resolved by switching to the second chemical if a strain that is resistant to the first one starts to form (Maillard, 2018). (Maillard, 2018).

c) Water and chemical compatibility: Verify that the biocide is safe to use with your water. In higher brines, some will precipitate or salt out. Additionally, it is necessary to determine compatibility with corrosion or scale inhibitors (Colon et al., 2020, Morris and van der Kraan, 2017).

d) Time-Kill Tests: Any bactericide must be applied gradually in order to eradicate the bacteria. Consequently, it is prudent to ascertain the duration required for a specific chemical to function at various chemical concentrations. A laboratory is required to do this. API RP 38 lays out a particular procedure for sulfate reducers. In the API-RP38 standard, the American Petroleum Institute suggested using API Media as a formula to monitor SRB in oil and gas systems (Ramachandran et al., 2021). Understanding the time-kill relationship is crucial, particularly when batch treatment is being used.

6.4 Treatment Method

The method of treatment must also be taken into account. Lower chemical concentrations can typically be effective after the bacterial population has been brought under control, but if the biocide is to be continuously injected, a high concentration is usually needed initially to do so. Laboratory tests can be used to estimate this minimum. In order to achieve a high concentration, pipeline treatment biocide must be injected between two pigs. Equipment such as tanks and vessels that administer shock dosages exceeding 1000 parts per million will be used for a considerable amount of time during downhole treatment batch treatment. A high concentration slug is periodically pumped through the system if batch treatment is to be used, and the result is a complete kill. Time-kill tests can be used to determine the concentration, slug size, and contact time in this case, and experience can then be used to modify the results (Abdalsamed et al., 2020, Senthilmurugan et al., 2019, Pereira et al., 2021). Since stagnant water provides an ideal environment for bacteria to establish a kingdom and grow quickly, it must be removed from the system (Zhang et al., 2020).

5.6 Electrochemical Protection

The potential to produce an alkaline environment near the cathode surface can be managed in order to effectively inhibit microbial activity. For instance, a voltage lower than -0.95 V, which is equivalent to the $Cu/CuSO_4$ reference electrode, can be applied to steel components to protect them. The best outcomes will come from combining this with the overlay method.

6.6 Physical Methods and Coating

The employing methods like UV, ultrasonic, and radiation to get rid of corrosive bacteria. Paint or another coating can help shield the metal from corrosive environments. It is possible that the topcoat contains antibacterial materials like zinc or chromium plating. The metal surface can be coated with these materials using epoxy coating, polyethylene, cement, asphalt, and other corrosion prevention methods.

6.7 Stagnant Water

It is necessary to remove stagnant water from the system because it provides an ideal environment for bacteria to grow and establish their kingdom. Additionally, it is a good environment for all salts to begin attacking metals.

7. Corrosion Rate Investigation

Sulfate Reducing Bacteria analysis requires the use of an ERP instrument and a corrosion coupon to investigate the rate of corrosion(Abdalsamed et al., 2022).

Conclusion

The study of microbial activity and its effects on corrosion is critical in managing the integrity and efficiency of oilfield and water injection systems. Sulfate-reducing bacteria, iron bacteria, and slime-forming bacteria are among the most significant contributors to microbiologically influenced corrosion (MIC). Their ability to create biofilms and produce corrosive by-products such as hydrogen sulfide accelerates metal deterioration, resulting in significant economic and operational challenges.

Addressing these issues requires a combination of prevention, monitoring, and treatment strategies. Regular bacterial counts, effective biocide applications, and the elimination of favorable growth conditions such as stagnant water are essential measures. Chemical biocides, while widely used, must be carefully selected and periodically alternated to prevent the emergence of resistant bacterial strains. Additionally, complementary methods, including physical coatings, electrochemical protection, and the use of UV or ultrasonic treatments, provide valuable layers of defense.

The challenges associated with microbial corrosion highlight the need for innovation. Future efforts should focus on developing eco-friendly and efficient alternatives, such as nanotechnology-based tools or leveraging beneficial microorganisms to counteract harmful bacteria. Research in these areas could lead to safer and more sustainable solutions, reducing reliance on harsh chemicals and minimizing environmental impact.

Ultimately, mitigating microbial corrosion requires a multidisciplinary approach that combines scientific research, practical application, and technological advancement. By adopting proactive strategies and embracing innovation, industries can protect valuable infrastructure, reduce maintenance costs, and ensure safer operations. This comprehensive approach will also contribute to addressing the long-term sustainability challenges faced by the oil and gas sector.

Future Work

Based on their ongoing research into the elimination of bacteria, including sulfate reducing bacteria, by other organisms, microbiology scientists are working to create nanotools that are safer than chemicals for killing bacteria.

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