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The mechanism and control methods of microbiologically induced corrosion on the pipeline

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ABSTRACT

The study summarized the mechanism of Microbiologically Induced Corrosion, introduced the damage which MIC bring to industry，production and life，focused on the mechanism of MIC caused by the two main strains of iron bacteria and sulfate-reducing bacteria, and puts forward to the prevention and control of MIC of chemical, physical and biological methods. And it analyzed the principles and the merits and demerits of various control methods，according to the specific situation to choose suitable control method, or joint control methods can be used.

Key words: Microbiologically Induced Corrosion, Iron bacteria, SRB, Control methods, Pipeline

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INTRODUCTION

The phenomenon of metal corrosion caused and promoted by the life activities of microorganisms is known as Microbiologically Induced Corrosion，which is referred to as the MIC. All facilities contact with the water, soil or wet air are likely to encounter MIC. The harm of the MIC is hazardous, cooling water circulation system of power plant , heat exchanging system, oil exploration, sewage pipe, water pipe, and reclaimed water pipe have varying degrees of microbial infection and microbial corrosion. According to statistics, microbial corrosion in the metal and building materials of corrosion damage accounted for 20%，direct losses caused by microbial corrosion is about $300\text{-}500\times10^8$ dollars a year[1].So it is meaningful to research on MIC of metal.

MIC is not effect on the corrosion of the metal by itself, but rather the result of microbial life activities indirectly impact on metal corrosion electrochemical process. When the metal surface exist of microbial membrane, pH value, the concentration of dissolved oxygen, kinds and concentrations of organic and inorganic substances of the interface between the metal surface / microorganisms, are greatly different from the bulk solution, in the reaction of the biofilm changed the mechanism and the rate of corrosion[2].Basically has the following four ways:

(1) Metabolic products, the corrosion of such as acid, alkali , sulfide and other harmful ions.(2)The activity of microorganism directly affect the process of electrode reaction kinetics.(3)Due to microbial activity on the interface of metal electrolyte caused the change of the state, resulted in the occurrence of corrosion, such as the formation of oxygen concentration cell.(4)Damage on the surface of the metal and non-metallic coating and undermine the stability of the corrosion inhibitor.

2. The mechanism of MIC

Microbiologically induced corrosion (MIC) of the pipe is in the case of the presence of microorganisms, their life activities in the pipeline，and interact with the environment, resulted corrosion of the pipeline. Microbial metabolic processes occur simultaneously with electrochemical corrosion[3], in order to promote each other with electrochemical corrosion, leading to corrosion of the pipeline. Two kinds of microbial lead to the corrosion in the pipeline, which were respectively aerobic bacteria, such as iron bacteria and anaerobic bacteria, such as sulfate reducing bacteria. Because of the special circumstances of the pipe, the two types of bacteria are exist and be able to breed, their metabolic activity interrelated and commonly led to the happening of the microbial corrosion.

2.1 The corrosion mechanism of iron bacteria

The mechanism of MIC of iron bacteria because of iron aerobic bacteria，iron bacteria so inseparable from the role of oxygen. Iron bacteria having the ability to produce iron hydroxide sediments, iron bacteria has the capable of oxidation of Fe^{2+} to Fe^{3+} ions and use energy to grow, eventually form $Fe(OH)_3$ precipitation[4].Studies suggest that [5]，iron bacteria mainly take part in the corrosion in the form of corrosion scale，and in a short time to produce a large number of iron oxide deposition. The corrosion of iron bacteria occurs through the crevice corrosion mechanism[6]，iron-oxidizing bacteria of effect on the high concentration of oxygen and the metal surface into the small anode spot(under the dense iron hydroxide and products) and a wide range of cathode region[7]. As iron bacteria formed oxygen concentration cell on the inner wall of the pipe, the reaction is [8]:

$2Fe \rightarrow 2Fe^{2+}+4e$ （Anodic reaction）
$O_2+2H_2O+4e \rightarrow 4OH^-$ （Cathode reaction）
$2Fe^{2+}+4OH^- \rightarrow 2Fe(OH)_2$ （Corrosion products）
$4Fe(OH)_2+O_2+2H_2O \rightarrow 4Fe(OH)_3$ （Corrosion products）

The total equation is:

$$4Fe+3O_2+6H_2O \rightarrow 2Fe(OH)_3$$

Iron bacteria often work associated with other microorganisms (SRB), such as iron bacteria produce iron-rich and anaerobic environment in which to SRB proliferation, SRB interact with iron bacteria can accelerate the corrosion process of pipe networks [3].

2.2 The corrosion mechanism of SRB

Currently the mechanism of SRB, basically has the following theory: cathodic depolarization theory, concentration cell theory, metabolites corrosion theory.

2.2.1 Cathodic polarization theory

Kuhr and Vluglt [9] proposed the classical theory of cathodic depolarization of SRB corrosion , it is the main mechanism of SRB corrosion, he believed that under hypoxic conditions, SRB cathodic depolarization effect to remove the hydrogen atoms from the metal surface, so that the corrosion process continue. Reaction is as follows:

$4Fe \rightarrow 4Fe^{2+}+8e$ （Anodic reaction）
$8H_2O \rightarrow 8H^++8OH^-$
$8H^++8e \rightarrow 8H$ （Cathode reaction）
$SO_4^{2-}+8H \rightarrow S^{2-}+4H_2O$ （SRB cathodic depolarization）
$Fe^{2+}+S^{2-} \rightarrow FeS$ （Corrosion products）
$3Fe^{2+}+6OH^- \rightarrow 3Fe(OH)_2$ （Corrosion products）

Corrosion products are generated by the above two reactions. The total equation is:

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

2.2.2 Concentration cell theory

Starkey[10] considered that part of the metal surface coveraged dirt and corrosion products (such as iron hydrates) , will form the gas difference or concentration cell. In many cases, this type of corrosion associated with anaerobic corrosion, because of the formation of the living environment suitable SRB[21].

2.2.3 Metabolites corrosion theory

In the process of SRB growth and metabolic activity, can produce a certain amount of sulfide, due to the role of sulfide accelerated corrosion of metal[11,13]. The anaerobic corrosion of SRB is also due to the result of their metabolism produce the highly active and volatile phosphide，phosphides and iron substrate, SRB generated H_2S,hypophosphite and iron can produce Phosphating of iron, exacerbated the substrate corrosion of iron. Corrosion product film formed by SRB metabolites (such as Fe^{2+}, H_2S and phosphide) will accelerate the local corrosion of the metal.

2.2.4 The acid corrosion theory under sediments

The important basis of acid corrosion theory is the vast majority of the final product of MIC is low-carbon-chain fatty acids (such as acetic acid). When the carbon-chain fatty acid concentrated in sediment microbial corrosion of metals is very aggressive. In the oxygen atmosphere，the region immediately below the sediment relative to surrounding large cathode become small anode. The cathodic reduction reaction of oxygen resulted in the pH of the solution around the metal becomes large. Metal forming metal cation in anode area. If the metal hydroxide in solution is thermodynamic stability, metal ions can be hydrolyzed into H^+. If the anode zone and cathode zone is isolated, pH value of the anode will decrease and the pH of the cathode region will increase[12,14].

3. Control methods of MIC

3.1 Chemical control methods

Chemical control methods are adding to the water of various fungicides, bactericides to kill the microbes is main mechanism of fungicide penetrate into the cytoplasm, destruction of protein genes in the cells body, so that makes microbial death. Chemical fungicide generally divided into two categories: oxidation type and non-oxidation type. Oxidizing biocides mainly such as chlorine, chlorine dioxide，bromine，ozone，etc.，non-oxidizing biocides mainly chlorophenol，glutaraldehyde，quaternary ammonium salts，isothiazolin-ketone.

3.1.1 Oxidation fungicide

Chlorine dioxide almost 100% with molecular states exist in the water，so easily through the cell membrane. Chlorine dioxide available chlorine content is 263%, therefore, its sterilization effect is significantly more liquid chlorine is strong, which is about 2.5 times that of the liquid chlorine. Chlorine dioxide disinfection can make the generation of chloroform in water reduced by 90%, and can prevent the generation of chlorophenol smell systematically[15]. In addition to kill the general bacteria , iron bacteria, sulfate reducing bacteria, fungi, algae and spore, the virus have the very good killing effect. The disadvantage is that because of its low boiling point (11℃), cannot transport, so must be prepared with the site preparation.

3.1.2 Non-oxidizing biocides

Types of non-oxidizing biocides are many，they are often used interchangeably with oxidizing biocides in water systems to prevent microorganisms resistant in water.

Aldehyde of fungicide aldehyde group played a main role in killing microorganisms, their main effect on bacteria protein hydrophobic base, hydroxyl, carboxyl and amino, alkylation, protein by killing bacteria[22]. Aldehyde fungicide is using in a very wide range, sterilization effect is good. But most of aldehyde fungicide are toxic, long-term use can also cause harm to humans，and it will produce pollution to the environment.

3.1.3 New corrosion inhibitor

In recent years the researchers are more committed to the development of new environmental friendly corrosion inhibitors.Rare earth metals in the role of various corrosion of the system with high efficiency.3-fennel fork amino 1, 4-trichlorobenzene triazole phosphate (AATP) for carbon steel in aqueous solution is a good corrosion inhibitor [16]. In addition，there are also studies of the amino acids green corrosion inhibitors[17].

3.2 Physical control methods

Physical control method can be mainly divided into three categories: The first category is through a variety of ionizing radiation，electric field and magnetic field to kill microorganisms, common technology is ultraviolet sterilization, γ-ray sterilization, sterilization，electromagnetic and so on；the second category starts from material , such as coated with a protective coating，developing and applying of corrosion resistant materials; the third category is using electrochemical techniques such as cathodic protection. Because these methods produce almost no pollution to the environment and they are energy saving. So they are widely used and have good prospects for development.

3.2.1 Rays，electromagnetic sterilization

Usually around 260 nm wavelength ultraviolet ray has the very strong radiation, and the wavelength was absorbed by nucleic acid, thus prolong irradiation time can kill iron bacteria; γ and X-ray can make the two connected thymidine in the DNA chain cause covalent connectivity and make its replication errors, thus death[18]. In addition, use ultrasound or radiation treatment also can kill the iron bacteria.

3.2.2 Cathodic Protection

The methods to protect the exposed metal surface can be divided into sacrificial anode and impressed current method[19].Using cathodic protection and good coating together is the effective measure to prevent or mitigate corrosion.

3.3 Biological control methods

Biological control method using relationship of symbiosis，competition and antagonism between microbial to prevent microbial corrosion of metal. Biological control usually uses phage method. It is using natural enemies of the bacterial phage to prevent and eliminate microbial membrane in water system. It is a quite promising biological methods[20].

CONCLUSION

Microorganisms involved in various industrial departments, with the development of the industry, the MIC will become more and more prominent. Research on the mechanism of MIC are ongoing continues. Many theories exist shortcomings and deficiencies, generally considered that only use one theory to explain the mechanism of MIC seems too simple, in the process of microbial corrosion, which involves many factors, such as the material of pipe materials, shape, and environment and so on. In many cases, the corrosion is caused by a variety of common microorganisms such as the metabolic activity of aerobic microorganisms to create an anaerobic environment to sulfate-reducing bacteria in which the sulfate-reducing bacteria to multiply, and thus accelerate corrosion. Thus in view of the corrosion mechanism for complex interleaving, various prevention and control methods of microbiologically induced corrosion should be applied together in order to achieve the purpose of control the corrosion.About microbiologically induced corrosion, there are still many problems to be solved, to address these issues in order to promote the development of prevention and control of MIC of new technologies.

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REFERENCES

[1] Yuan S J；Pehkonen S O. *Corrosion Science*, **2009**, 51(6): 1372-1385.
[2] Wagner P；Little B. *Materials Performance*,**1993**,9:65-68.
[3] Congmin Xua；Yaoheng Zhang；Guangxu Cheng；et al. *Materials Science and Engineering*,**2007**,443:235-241.
[4] David S.；Robert A.；Josef Y.；et al.. *Int. Biodet.&Biodegrad*, **2001**,47,79-87.
[5] Ehrlich H.I. In:Geo-microbiology, M.Dekker, *New York*, **1996**, 338.
[6] Tuhela I；Carlson I；Tuovinen O.H. *Wat. Res.***1992**, 26(9):1159-1162.
[7] Borenstein S.W..Microbiologically influenced corrosion handbook,Cam-bridged. *Wood head*, London, **1994**,12.
[8] Cloet T.E.；Brozel V.S.；Von Holy A.. *Int.Biodet.& Biodegrad*,**1992**,29,299-341.
[9] Von Wolzogen Kuhr C A；Vander Vluglt L S；De Grafi-teering. *Corrosion*, **1984**, 18(6): 147.
[10] Starkey R L. *Producers Monthly*, **1958**,22: 12-16.
[11] Li Yingxia；Gong AiJun. *Comprehensive corrosion control*, **2005**, 19(1)30-33.
[12] Evans T E；Chart A；Skedge A.N. *Trans Inst of Metal Finish*,**1973**,51（3）：108-112.
[13]Liao Xiaozhen；Zhu Xinyun；et al. *Electroplating*，**1995**,14（3）：19-21.
[14] King K A. *Nature*, **1971**, 233(5): 491.
[15] Wang hua. Sulfate-reducing bacteria on the corrosion mechanism of several metal materials research [D]. *Dalian: Dalian university of technology*，**2010**.
[16] Ge GongHua；Zhou Guoding；XieQun. *North China electric power university*, **2005**, 33(9): 13-14.
[17] Zhao Li. Microbial corrosion in cooling water and its control research [D]. *Shanghai*: *Shanghai institute of electric power*，**2011**.
[18] Lang sequence fe；Qiu Lina Gong；AiJun, etc. *Comprehensive corrosion control*, **2009**, 23(10): 20-24.
[19] Child；Ms. Li；kit；et al. *Chemical industry are reviewed*,**2004**, 23(7): 719-723.
[20]Chen Junqin；Lu hao. *Applied ecology*, **1994**, 5(1): 83-88.
[21] Abedi S Sh；Abdolmaleki A；Adibi N. *Engineering Failure Analysis*,**2007**,14(1):250-261.
[22] Wan Y；Zhang D；Liu H Q；et al. *Electrochimica Acta*, **2010**, 55(5): 1528-1534.