RESEARCH ARTICLE OPEN ACCESS

Assessment of effect of corrosive microorganisms on metal

Svetlana Aitkeldiyeva, Elmira Faizulina, Olga Auezova, Larissa Tatarkina, Aray Nurmukhanbetova, Amankeldy Sadanov
Institute of Microbiology and Virology, Kazakhstan
E-mail: ecomicrolab@gmail.com

ABSTRACT
One of the actual problems of damage to metal structures is microbial corrosion. Activity of microorganisms caused up to 80% of corrosion damage. We studied the effect of heterotrophic denitrifying microorganisms, thionic and sulfate-reducing bacteria on metal plates during cultivation in a liquid medium. It has been established that the most corrosive microorganisms are thionic bacteria. When they were cultivated, the weight loss of steel plates was 28.5-59.9% for 3 months. CRB also cause corrosion of the metal, but during the experiment the rate of failure of the metal was low. Heterotrophic denitrifying microorganisms slow down the process of metal corrosion due to the formation of biofilms on its surface.
***Keywords*:** corrosion, biocorrosion, thionic bacteria, sulfate-reducing bacteria, denitrifying bacteria, biofilm

I. INTRODUCTION

Microbial corrosion is part of the most urgent problem of biodeterioration. Among the most susceptible to biological corrosion facilities, there are conduct pipes, petroleum pipelines, tanks, piles, and other underground pipeworks, as well as reinforced concrete structures and constructions. The activity of microorganisms, according to some authors, can cause 50 to 80% of corrosion damage [1, 2].

The effect of microorganisms on metals can occur in different ways. First of all, aggressive metabolites of microorganisms including mineral and organic acids and bases, enzymes and others cause metals to corrode. Colonies of microorganisms form outgrowths and mycelial or mucus films on the surface of metals, under which ulcerative (pitting) corrosion may develop [3, 4, 5].

The most active corrosive agents comprise thionic and nitrifying bacteria that create acidic aggressive environments, as well as sulfate-reducing bacteria (SRB), which produce corrosive metabolites, such as NH_3, CO_2, H_2S, organic and mineral acids [6,7].

Thionic and nitrifying bacteria, as well as iron bacteria, are the causative agents of aerobic corrosion, which is observed when there is a sufficient amount of free or dissolved oxygen in water. As a result of their vital activity, aggressive corrosive environments are produced through the accumulation of sulfuric and nitric acids, the final products of their metabolism. Drainage concrete and water-supply steel pipes, pumps, and various equipment in mines, steel constructions of underground structures, stone and concrete structures, etc., are susceptible to aerobic corrosion [8].

Anaerobic corrosion is observed under oxygen-free neutral conditions. Cases of this type of corrosion are more typical for underground structures and constructions located in dense clay- and water-bearing layers of soil. Sulfate-reducing bacteria are the major agents of anaerobic corrosion. The corrosion under their effect is mainly due to the formation of hydrogen sulfide and sulfides as a result of sulfate reduction. SRB-induced corrosion behavior of iron and steel is usually local and pitting. The corrosion products have the characteristic black color, odor of hydrogen sulfide, and slightly adhere to the surface of the metal, which under their layer retains a shiny surface [9, 10].

In recent years, the participation of denitrifying microorganisms in corrosion processes is attracting increasing attention from the researchers. It is believed that denitrifying bacteria are involved in the corrosion of metal equipment located in the ground and below the water, as well as heat exchange systems. As a result of the vital activity, this group of bacteria produces organic acids that exert a corrosive attack on metals [11].

II. MATERIALS AND METHODS

To determine the corrosive activity of denitrifying heterotrophic bacteria, two plates made of grade 3 steel were placed into the test tubes filled to 2/3 with Giltay's medium, and 1 ml of a bacterial culture suspension was added. Corrosive activity of sulfate-reducing bacteria was determined using Postgate's medium under anaerobic conditions. The activity of *Thiobacillus* *denitrificans* bacteria was examined in Baalsrud's medium, and that of *Thiobacillus ferrooxidans* bacteria in 9 K medium. To develop thionic bacteria, 200 mg of alcohol-sterilized elemental sulfur were also added to the media.

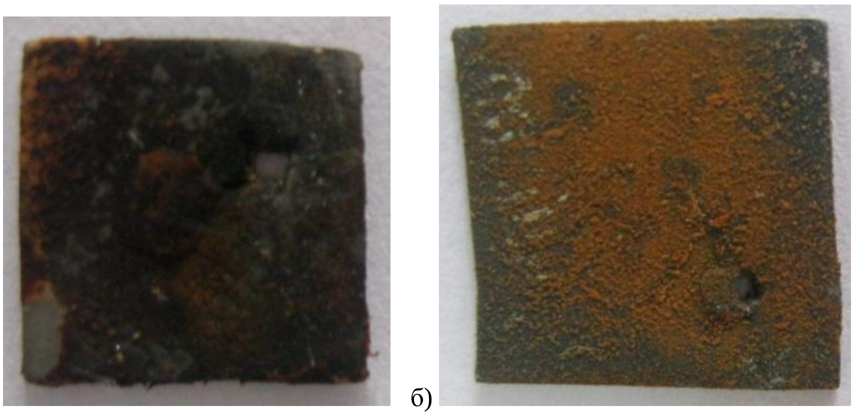
The steel plates were previously polished, weighed, and treated with alcohol. The control variant was not inoculated with bacteria. The tubes were placed in a thermostat at a temperature of 28 °C. The results of the experiment were recorded after the periods of 1, 2, and 3 months. Corrosive activity was estimated by the weight loss of the plates. To this end, they were treated with a liquid for removing corrosion products of the following composition: H_2SO_4 (conc.) - 84 g (46 ml), ammonium citrate 2-substituted ($C_6H_{14}O_7N_2$) - 100 g, thiourea - 10 g, distilled water - 880 ml [12]. The plates were weighed after the treatment.

III. RESULTS AND DISCUSSION

To assess the degree of corrosive activity of microorganisms, the model experiments were performed with the samples isolated from the reinforced concrete surfaces deteriorated by heterotrophic denitrifying bacteria, SRB, *Thiobacillus denitrificans*, and *Thiobacillus ferrooxidans*. We have isolated 8 strains of denitrifying bacteria and 5 SRB strains, 5 isolates of *Thiobacillus denitrificans*, and 3 isolates of *Thiobacillus ferrooxidans*. The strains of denitrifying microorganisms DM1 and DM3, which reduced nitrates to molecular nitrogen, were selected for the experiments. Among the sulfate-reducing bacteria, the strains SRB 4 and SRB 5 were selected which showed the most intensive growth on Postgate’s B medium. Among the *Thiobacillus ferrooxidans* isolates, Tf-3 was selected that exhibited active growth on 9K medium, as well as Td-1 among the *Thiobacillus denitrificans* isolates, which grows well on Baalsrud’s medium.

The experiments were performed with all selected strains in liquid media which were optimal for their growth. The steel plates placed into sterile media without inoculation with microorganisms served as control.

The results of the experiment to determine the degree of the corrosion of the plates made of grade 3 steel under the effect of denitrifying microorganisms are presented in Figures 1 and 2.



а) б)

а) – control, б) – strain DM1

Figure 1 – The plates of steel-3 after incubation with heterotrophic denitrifying bacteria

It was shown that when incubated with the DM1 and DM3 strains, the degree of corrosion of the steel plates was lower as compared with control. Under the influence of the DM1 strain, the weight loss of the steel plates was 2.35% after 2 months, and it reached 3.37% with the DM3 strain. In control, the weight loss of the plates was 3.67%. After 3 months, the weight of the plates was reduced by 3.2% and 4.5% under the effect of the cultures under study and by 4.7% in the control variant.

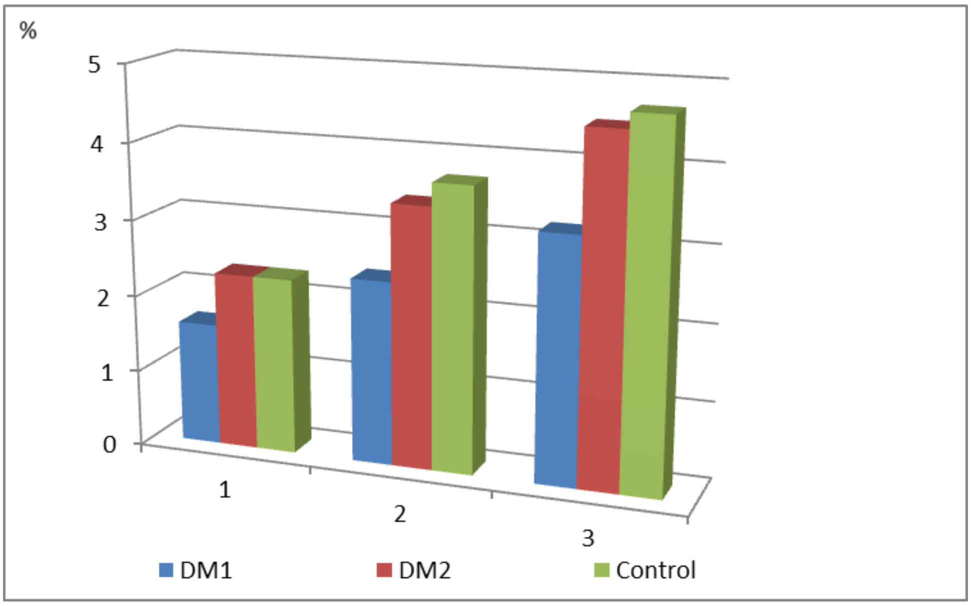
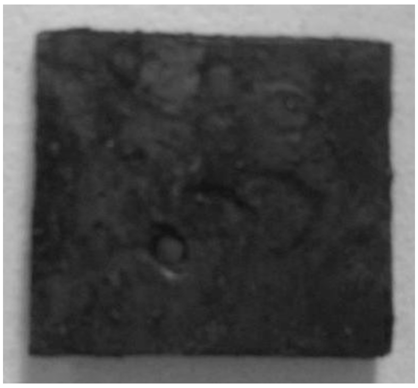


Figure 2 - The weight loss of steel plates during incubation with strains of denitrifying microorganisms

According to the literature data, there are species of microorganisms that can inhibit corrosion by slowing the ion exchange between the metal surface and environment. Microbes stimulate corrosion by forming an additional galvanic pair between the biofilm bacteria and metal surface. Under oxygen-free conditions, the biofilms act as a cathode, a metal acts as an anode, and electrons flow from the metal to cells. The positive charge on a metal increases and is retained as long as the activity of the bacteria is maintained. On the contrary, with microbial inhibition of corrosion, the bacteria act as an anode and a metal as a cathode. Oxygen consumption by generations of bacteria reduces the rate of an electron detachment from the metal surface. Accordingly, the process resembles the principle of non-biological cathodic protection of metals, which is usually used to protect against corrosion [13, 14, 15, 16].

It was found that corrosion of the steel plates during incubation with SRB was more intensive as compared with control. The formation of iron sulfide on the metal surface (blackening) which is a highly corrosive agent contributing to an acceleration of the corrosion process, was seen in the experimental variants on the steel plates after 3 months of incubation with the strains of sulfate-reducing microorganisms SRB 4 and SRB 5 (Figure 3).

a)  б) 

a) – control, б) – SRB 4 strain

Figure 3 - The plates of steel-3 after incubation with sulfate-reducing bacteria

When incubated with the SRB 4 strain, the weight loss of the plates was 1.21% after 2 months, and 1.0% with the SRB 5 strain, while in the control the loss was 0.83% (Figure 4).

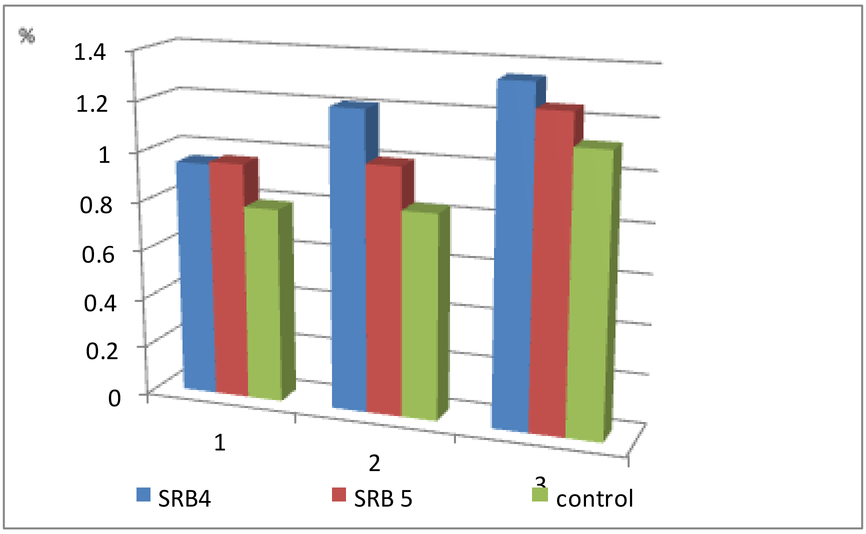
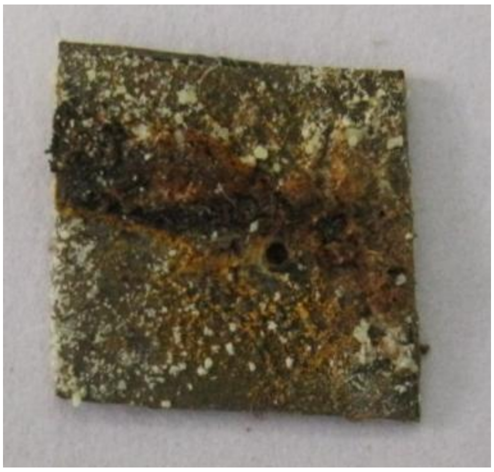


Figure 4 – The weight loss of steel plates during incubation with SRB strains

During the 3rd month, the weight of the plates continued to be reduced. The greatest weight loss (1.35%) was observed when the SRB 4 strain was cultivated. Under the effect of the SRB 5 strain, the weight of the plates was reduced on average by 1.25%, while in the control the weight loss was 1.12%.

The examination of the steel plates after incubation with the *Thiobacillus denitrificans* isolate Td-1 during three months showed that the loss of their weight occured much faster as compared with control, which indicates high corrosive activity of this isolate (Figure 5).

а)  б) 

а) – control, б) – Td-1

Figure 5 - The plates of steel-3 after incubation with bacteria *Thiobacillus denitrificans*

It was shown that the weight of the plates in the experimental variant after 3 months of incubation was reduced by 28.5%, while in the control variant the weight loss did not exceed 1.2% (Figure 6). Therefore it can be said with certainty that with the apparent non-aggressiveness of the culture medium, the bacteria of the *Thiobacillus denitrificans* isolate Td-1 are highly corrosive.

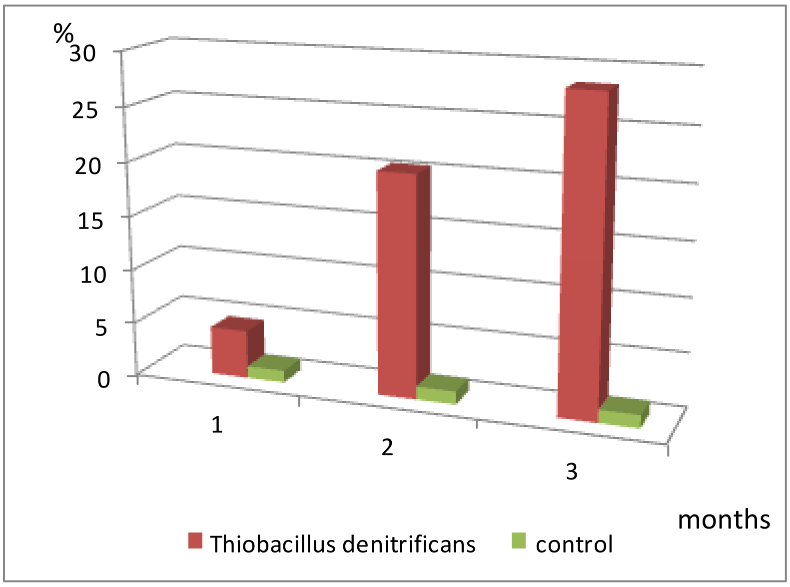
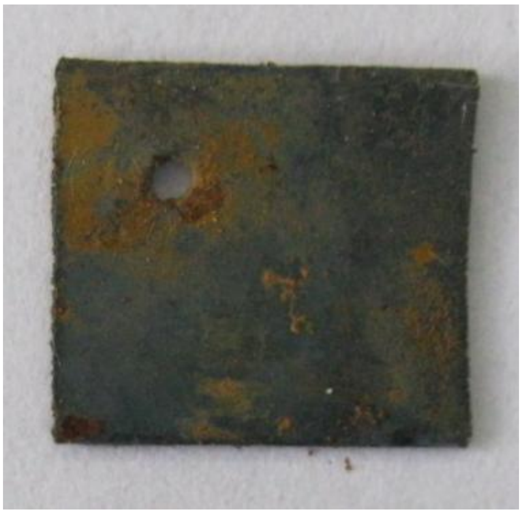


Figure 6 - The weight loss of steel plates during incubation with the strain of *Thiobacillus denitrificans*

When the steel plates were incubated with the *Thiobacillus ferrooxidans* isolate Tf-3, the the most intensive corrosion was observed after a 3-month period (Figure 7).

a)  б) 

a) – control, б) – Tf-3

Figure 7 – The steel-3 plates after incubation with *Thiobacillus ferrooxidans*

It should be noted that the culture medium is aggressive by itself (pH 3.0). In the control variant, the weight loss of the plates for 3 months was 4.0%, 11.4%, and 25.5%, respectively (Figure 8). However, the high corrosive activity of bacteria belonging to the genus *Thiobacillus ferrooxidans* is beyond doubt. It was found that a month later the weight of the plates in the experimental variant decreased by 19.1%, after 2 months - by 28.4%, and after 3 months - by more than half (59.9%).

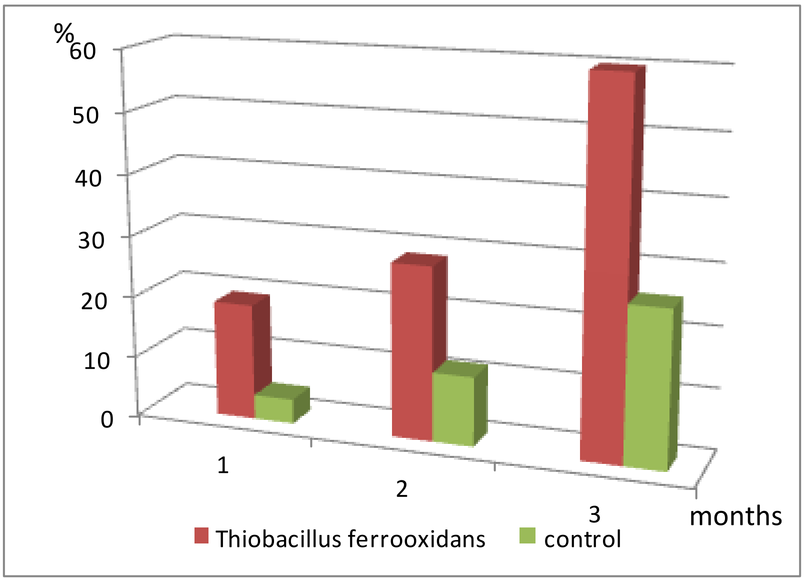


Figure 8 – The weight loss of steel plates during incubation with the strain of *Thiobacillus ferrooxidans*

It has thus been established that the *Thiobacillus ferrooxidans* and *Thiobacillus denitrificans* bacteria are the most corrosive microorganisms. When they were cultivated, the weight loss of steel plates over a 3-month period was 59.9% and 28.5%, respectively. SRB also induce the metal corrosion, but the deterioration rate of the metal was low during the experiment. Heterotrophic denitrifying microorganisms form a biofilm on the metal surface, which slows down its corrosion process.

LITERATURE

[1]. Chesnokova M.G., Shalaj V.V., Kraus Ju.A., Mironov A.Ju., Assessment of soil biocorrosion severeness on the pipeline locations, *Procedia Engineering*, *113*, 2015, 57 – 61.

[2]. Pankaj Sharma, Microbiological-Influenced Corrosion Failure of a Heat Exchanger Tube of a Fertilizer Plant, *J. Fail. Anal. and Preven.*, *14*, 2014, 314-317.

[3]. Beech I.B., Gaylarde Ch.C., Recent advances in the study of biocorrosion - an overview, *Rev. Microbiol., 30 (3)*, 1999, 177-190.

[4]. Ashassi-Sorkhabi H., Moradi-Haghighi M., Zarrini G., Javaherdashti R., Corrosion behavior of carbon steel in the presence of two novel iron-oxidizing bacteria isolated from sewage treatment plants, *Biodegradation*, *23*, 2012, 69-79.

[5]. Moreno D.A., Ibars J.R., Polo J.L., Bastidas J.M., EIS monitoring study of the early microbiologically influenced corrosion of AISI 304L stainless steel condenser tubes in freshwater, *J. Solid State Electrochem.*, *18*, 2014, 377-388.

[6]. Moiseeva L.S., Kondrova O.V., Biocorrosion of Oil and Gas Field Equipment and Chemical Methods for Its Suppression, *Protection of Metals*, *41 (4)*, 2005, 385-393.

[7]. Sandrine Païssé, Jean-François Ghiglione, Florence Marty, Ben Abbas, Hervé Gueuné, José Maria Sanchez Amaya, Gerard Muyzer, Laurent Quillet, Sulfate-reducing bacteria inhabiting natural corrosion deposits from marine steel structures, Appl. Microbiol. Biotechnol., 97, 2013. – Vol.. – P. 7493-7504.

[8]. Bykov A.G., Polivtseva V.N., Abashina T.N. and Vainshtein M. B., Inhibition of Microbiological Corrosion of Concrete by Nickel Sulfide, *Protection of Metals and Physical Chemistry of Surfaces*, *51 (7)*, 2015, 1194-1197.

[9]. Moiseeva LS, Polyakova AV, Zeleny M.T., Perfection of the methods for controlling the contamination of oilfield environments and the bactericidal action of chemical reagents with respect to SBS, *Corrosion: materials, protection*, *5*, 2012, 42-48.

[10]. L.T. Dall' Agnol, J. J. G. Moura, Sulphate-reducing bacteria (SRB) and biocorrosion, in: T. Liengen, R. Basseguy, D. Feron, I. Beech and V. Birrien, Understanding Biocorrosion. Fundamentals and Applications, 4 (Woodhead Publishing, 2014) 77–106.

[11]. Andreyuk E.I., Bilai V.I., Koval E.Z., Kozlova I.A., *Microbial corrosion and its agents* (Kiev: Naukova Dumka, 1980).

[12]. 12 Andreyuk E.I., Kozlova I.A., Kopteva Zh.P., *Microbial corrosion of underground structures* (Kiev: Naukova Dumka, 2005).

[13]. Nozhevnikova A.N., Botchkova1 E.A., and Plakunov V.K., Multi Species Biofilms in Ecology, Medicine, and Biotechnology, *Microbiology, 84 (6)*, 2015, 731-750.

[14]. Potekhina, J.S., Sherisheva, N.G., Povetkina, L.P., Pospelov, A.P., Rakitina, T.A., Warnecke, F., and Gottschalk, G., Role of microorganisms in corrosion inhibition of metals in aquatic habitats, *Appl. Microbiol. Biotechnol., 52*, 1999, 639-646.

[15]. Videla, H.A. and Herrera, L.K., Understanding microbial inhibition of corrosion. A comprehensive overview, *Int. Biodeterior. Biodegr., 63*, 2009, 896-900.

[16]. Purish L.M., Asaulenko L.G., Abdulina J.R., Vasil′ev V.N. and Iutinskaya G.A., Role of polymer complexes in the formation of biofilms by corrosive bacteria on steel surfaces, *Appl. Biochem. And Microbiol., 48 (3)*, 2012, 262-269.

Svetlana Aitkeldiyeva. “Assessment of effect of corrosive microorganisms on metal .” International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 9, 2017, pp. 56–62.