TECHNICKÁ UNIVERZITA V LIBERCI
Fakulta mechatroniky, informatiky a mezioborových studií

SKFM 2019
Studentská konference Fakulty mechatroniky, informatiky a mezioborových studií

Anaerobic microbially influenced corrosion of carbon steel in synthetic bentonite pore water inoculated by natural underground water: a 26-months study

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Widely accepted strategy for the management of the radioactive waste is to dispose the waste in deep geological formation. The safety will be ensured by multi-barrier system including metal canister. Microorganisms present in the repository may influence the long-term performance of safety of the barrier by various metabolic processes. Some of the anaerobic bacteria like sulfate and nitrate reducers are responsible for carrying out biocorrosion of the metal canister. We studied microbially influenced corrosion of carbon steel under anaerobic conditions for 26 months using weight loss method, surface analysis and molecular biology analysis.

Keywords: corrosion, microorganisms, carbon steel, radioactive waste repository

Introduction

The globally accepted strategy to dispose spent nuclear fuel and high level radioactive waste is deep geological repository (DGR). The concept of DGR entails a combination of engineered and natural barriers system. The absolute barrier of this disposal system is metal canister, which will prevent the direct release of radionuclides into the repository environment. Carbon steel is considered as a candidate canister material in Czechia as well as in several other EU countries. Safe performance of carbon steel canister may be, however, influenced by microbially induced corrosion (MIC), as many studies have shown active presence of anaerobic microorganisms in the natural underground water and bentonite buffer (Bengtsson and Pedersen, 2016) Sulphate-reducing bacteria (SRB) are considered potentially the most dangerous group of bacteria regarding MIC (Rajala et al., 2015).

The main aim of this study was to compare and characterize the corrosion behavior and resistivity of carbon steel under sterile and non-sterile anaerobic conditions in synthetic bentonite pore water (SBPW) inoculated with natural ground water VITA from Josef Underground Research Center (Czechia) containing a microbial consortium dominated by SRB.

Methodology

The test coupon was made of commercial low carbon steel C15E. The test specimens for electrochemical experiments measured 15 mm in diameter and 3 mm thick and the cylindrical carbon steel of diameter 10 mm and length 50 mm is used for investigation of weight loss (Fig. 1). The ratio of SBPW was inoculated with natural underground water was 9:1. MIC was studied using weight loss method (CSN ISO 8407, CSN EN ISO 9226), scanning electron microscopy (SEM) coupled with energy-dispersive spectroscopy (EDS) and Raman spectroscopy. Molecular-biological approach including qPCR analysis and next-generation 16S rDNA amplicon sequencing were used to determine the proliferation of relevant bacterial groups and to identify potentially harmful members of bacterial community. Experiment was run for 26 months with sampling time after 3, 6, 12, 18 and 26 months.

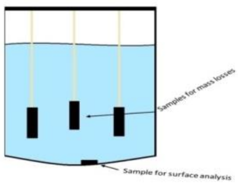

Fig: 1. Design experiment of weight loss experiment.

Results and discussion

In sterile conditions, uniform corrosion of carbon steel was observed and the corrosion rate decreased with increasing exposure time. Several local corrosion attacks were observed in non-sterile environment after 3, 6, 12 and 26 months and the corrosion rate of the non-sterile environment was up to 4 times higher compared to sterile environment (Fig. 3). Presence of microorganisms was confirmed by SEM and EDS analysis (Fig. 4). Raman analysis showed that the surface of carbon steel was covered with magnetite in the end of the experiment. In the case of non-sterile conditions, the mackinawite was detected on the carbon steel which can be attributed to metabolic activity of SRB (Fig. 5).

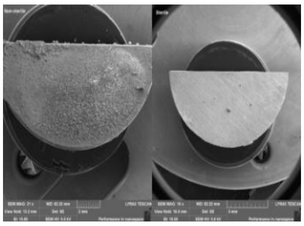

Fig: 2. Difference between non-sterile and sterile conditions on the surface of the samples collected after 26 months. On the non-sterile sample biofilm layer is visible

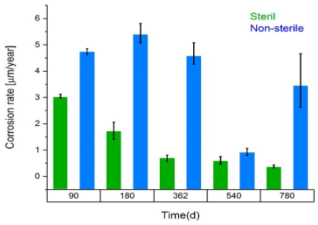

Fig: 3. Average corrosion rates based on weight loss method for the carbon steel in sterile and non sterile condition

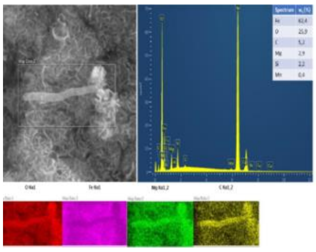

Fig: 4. EDS elemental maps of biofilm formed after 18 months . Element detected were Fe, O, C, Mg, Si and Mn

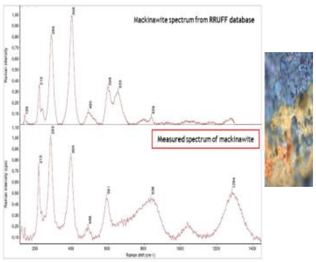

Fig: 5. Raman Spectra of the Carbon steel under non-sterile conditions after 12 months with the reference spectra of the macknawite (left) and the corresponding photo (right)

The relative abundance of total bacterial biomass and nitrate reducing bacteria (NRB) showed a fluctuation of microbial activity in time. Interestingly, microbial growth was observed after three months of incubation while a decrease was noticed after 18 months (data not shown). Members of NRB (relatively uncommon in the original underground water) found outcompeted SRB in the non-sterile sample (Fig. 6).

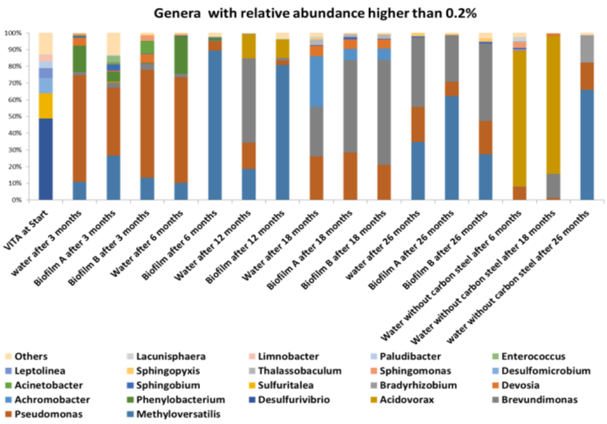

Fig: 6. Result of 16S rRNA amplicon sequencing of the microbial

This proliferation of NRB was caused by the high concentration of nitrate in the synthetic bentonite pore water, which mimics the Czech BaM bentonite leachate. It is known that nitrate reduction can be coupled with iron oxidation and thus leads to faster corrosion (Xu et al., 2013). The most common detected NRB genera in the biofilm were *Pseudomonas, Methyloversatilis* and *Brevundimonas*. No SRB were detected in the biofilm. Furthermore, the Principal coordinates analysis (PCoA) confirmed the existence of gradual shift in microbial composition in samples containing carbon steel during the experiment (Fig. 7)

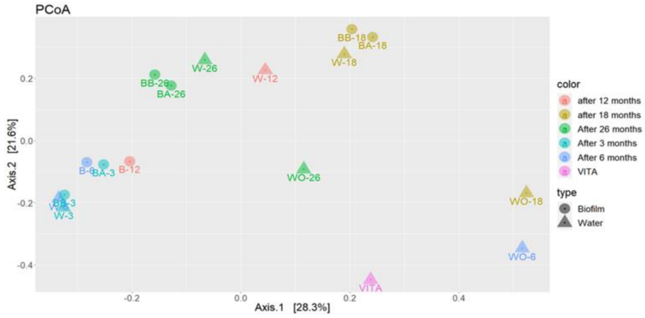

Fig: 7. Principal coordinats analysis (PCoA) based on frequency and composition of detected OTUs.

Conclusion

The corrosion rate of carbon steel in the non-sterile environment was up to 4 times higher compared to the sterile environment. SRB nearly disappeared and were replaced by microorganisms capable of nitrate reduction such as *Pseudomonas*, *Brevundimonas* and *Methyloversatilis.* The high abundance of *Methyloversatilis* correlates with the periods when the corrosion rates were the highest. Our results are relevant for the Czech waste disposal concept highlighting the necessity to consider NRB in addition to SRB as a potential threat for bio-corrosion of metal canister. The future studies should concentrate on this phenomenon.

Acknowledgement

This work supported by the Ministry of Education of the Czech Republic through the SGS project no. 21338/115 of the Technical University of Liberec and also by Euratom research and training programme, MIND 2014-2018 under grant agreement No. 661880.

Reference

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