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EVALUATION AND CONTROL OF MICROBIOLOGICALLY INFLUENCED CORROSION (MIC) OF A PIPELINE USING A BIOFILM SAMPLING DEVICE

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Microbiological analysis of bacteria in planktonic form leads to limited results in MIC evaluation and control. Therefore, employment in the process of a biofilm sampling device, in order to distinguish MIC from other corrosion mechanisms, is necessary. This device allows the evaluation of microbiological activity by biofilm accumulation and indicates the corrosive attack severity, which represent key factors in MIC control. This research consists in bacterial activity monitoring, laboratory analysis on biofilm and corroded disk coupons, corrosion monitoring of the pipeline and biocide treatment application, in order to evaluate and control MIC of an injection water pipeline.

Keywords: microbiologically influenced corrosion, biofilm sampling device, terraced pitting, biocide, corrosion monitoring

1. Introduction

Bacteria are encountered in two types of population, planktonic, freely existing in the fluid, and sessile, as a unit attached within a biofilm and responsible for MIC [1]. Sessile microorganisms are the most important biological component of the bacterial ecology of an oilfield in terms of corrosion [2].

MIC is localized corrosion that results from the presence or activity (or both) of microorganisms in biofilms on the surface of the metal. One characteristic of MIC is that while it does not produce a unique type of corrosion morphology, it is normally a localized form of corrosion damage [3]. Deep penetration into the base metal is observed and can take the form of pitting, crevice corrosion and under-deposit corrosion [4]. Pitting of steel has been observed to occur in regions covered by dense biofilms [5].

Biofilms consist of microorganisms held together with excreted slime, referred to as extracellular polymeric substances (EPS). EPS is composed of sticky, high molecular weight compounds and is abundantly produced by many microorganisms, rapidly coating the surface of steel in natural environments [6,7].

The most important bacteria associated with MIC are sulfate reducing bacteria, sulfur oxidizing bacteria, iron oxidizing/reducing bacteria, manganese oxidizing bacteria and bacteria secreting organic acids and slime [8].

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Monitoring programs for MIC have focused mainly on the assessment of planktonic populations in water samples and generalized corrosion by using corrosion coupons, which have provided limited results for the determination and evaluation of microbiological influenced corrosion.

Firstly, planktonic populations do not properly reflect the types and numbers of microorganisms living in biofilms and causing MIC problems. Secondly, the susceptibility of planktonic microorganisms to antimicrobial agents differs from that of sessile microorganisms within the biofilm, mainly because of the protective action of their EPS [9].

To understand the causes and effects of MIC requires an understanding of both the metallurgical and electrochemical aspects of corrosion as well as the microbial aspects of MIC related microorganisms. Monitoring strategies are necessary to understand microbiological activities and their effect on corrosion reactions [10,11].

The identification in the oilfield of metallic equipment, especially pipelines, corroded by microorganisms led to the decision to install a biofilm sampling device, in order to assess sessile bacteria and control MIC, specific for every reservoir.

The scope of this research is to evaluate microbiological activity in an injection water pipeline using a biofilm sampling device and to implement an efficient MIC control program, based on laboratory analysis of the biofilm and corroded disk coupons.

2. Experimental part

2.1. Biofilm sampling device

The biofilm sampling device (Fig. 1), hereinafter referred to as the device, was installed as by-pass of the injection water pipeline.

Fig. 1. The biofilm sampling device, installed as a by-pass of the injection water pipeline

The device is a metallic assembly, which has, among others, a collector and 4 valves. Throughout the monitoring program, the valves were opened, therefore the injection water has been continuously flowing through the device.

When the valves were closed, the collector of the device accumulated the biofilm containing sessile bacteria, the injection water and corrosion products. The collector was sealed, maintaining the proper conditions for generally anaerobic bacteria growth.

The collector contained 15 studs, exposed internally, with carbon-steel disk coupons, having similar metallurgy as the pipeline, for reproducing the effects of corrosion. The biofilm containing sessile bacteria was accumulated on the disk coupons.

In this research, chemical composition, surface roughness and microstructure of the disk coupons' metal correspond to non-alloyed carbon steel used for pipelines manufacturing.

2.2. Monitoring program

The microbiological activity and effect in the pipeline were monitored, using the device, in 5 monitoring campaigns, for 1.5 months, 2 months, 3 months, 2 months and, respectively, 2 months.

The previous experiments told us that the proper period for bacteria to accumulate and grow on the metal surface is about 2 months.

In this research, the periods of time for each monitoring campaign were established regarding several external factors, as the availability of the specialists and operators and well workover.

The injection water composition and operating conditions has been maintained as the same parameters during the monitoring program. However, unforeseen changes in operating, as suspended solids entrained in water flow and well acidizing treatment, influenced the experimental conditions. Injection water flow, pressure, temperature and composition are confidential, due to OMV Petrom internal regulations.

In every monitoring campaign, the collector of the device was transported to the laboratory to analyze the accumulated components (Fig. 2 and Fig. 3) and it was replaced with a clean one.

Fig. 2. The collector containing biofilm, the injection water and corrosion products

Fig. 3. The studs with disk coupons on which the biofilm accumulated

The general corrosion of the injection water pipeline was monitored, in the same period, using corrosion coupons installed in the proximity of the location.

The oilfield influence on corrosion and soil characteristics were not part of this research.

2.3. Microbiological analysis of the biofilm

The microbiological analysis of the biofilm was performed by the most probable number method. The bacteria associated with MIC were determined, considering the exposed surface of disk coupons of 63.62 mm^2.

Bacteria population was characterized by:

- high number, above 10^5 bacteria/surface;
- moderate number, 10^2 - 10^4 bacteria/surface;
- low number, below 10^2 bacteria/surface.

2.4. Microscopic examination of the biofilm

The biofilm was examined under optical microscope, in diluted form, with a light at 400 X magnification.

2.5. Microscopic examination of metal surface

The microscopic examination of corrosive attack on metal surface was performed using digital microscope and two-dimensional and three-dimensional images of surface morphologies were obtained.

2.6. Corrosion monitoring of the pipeline

The intensity of corrosion encountered in the injection water pipeline was monitored using corrosion coupons immersed in the injection water. The procedure was according to NACE RP0775 [12]. The corrosion coupons are manufactured of carbon-steel, a common material of pipelines.

The corrosion rate was determined by the formula:

$$Corrosion\ rate\ [\frac{mm}{year}] = \frac{weight\ loss\ [g] \cdot 8760\ [\frac{h}{year}]}{surface\ [mm^2] \cdot exposure\ time\ [h] \cdot density\ [\frac{g}{mm^3}]}$$

[12]

The microscopic examination of the surface of corrosion coupons was performed using digital microscope.

The corrosion intensity was classified, according to corrosion rate, as:

- low, under 0,025 mm/year;
- moderate, 0,025-0,12 mm/year;
- high, 0,13-0,25 mm/year;
- severe, above 0,25 mm/year [2].

2.7. Biocide treatment

The biocide treatment was applied in order to reduce the number of bacteria in the system and, therefore, to decrease the effect of MIC on metallic equipment.

The treatment was applied throughout the monitoring program.

The treatment consisted in 2 biocides, applied alternatively, every 2 weeks, at the lowest dose (50 ppm), considering the injection water flow of 800-1000 m^3/day.

The biocide was applied simultaneously with scale inhibitor in order to reduce the population of sulfate reducing bacteria and acid producing bacteria and, implicitly, the aggressiveness of MIC, and, respectively, to prevent and decrease the scale deposits which affect the pipelines integrity.

3. Results and discussion

3.1. Characterization of the biofilm

The biofilm was characterized by a diversity of bacteria causing MIC. The microbiological analysis revealed moderate and high populations of the most important bacteria in terms of MIC, sulfate reducing bacteria and acid producing bacteria. Also, other bacteria, aerobic and anaerobic, associated with MIC, were identified. The results of microbiological analysis of the biofilm are presented in Tables 1-5.

Table 1

Bacterial population identified in monitoring campaign no.1

Sample no.	Bacteria number/exposed surface				
	Aerobic Bacteria	Anaerobic Bacteria	Acid Producing Bacteria	Sulfate Reducing Bacteria	Iron Oxidizing Bacteria

1	10^4	10^2	10^2	10^3	10^2
2	10^4	10^3	10^2	10^3	10
3	10^5	10^4	10^2	10^4	10
4	10^5	10^4	10^3	10^4	10

Table 2

Bacterial population identified in monitoring campaign no.2

Sample no.	Bacteria number/exposed surface				
	Aerobic Bacteria	Anaerobic Bacteria	Acid Producing Bacteria	Sulfate Reducing Bacteria	Iron Oxidizing Bacteria
1	10^3	10	10^3	10^4	10
2	10^4	10^3	10^3	10^5	10
3	10^4	10^3	10^3	10^5	10
4	10^3	10^2	10^3	10^6	10

Table 3

Bacterial population identified in monitoring campaign no.3

Sample no.	Bacteria number/exposed surface				
	Aerobic Bacteria	Anaerobic Bacteria	Acid Producing Bacteria	Sulfate Reducing Bacteria	Iron Oxidizing Bacteria
1	10^4	10^2	10^3	10^2	10
2	10^5	10^2	10^4	10^3	10
3	10^5	10^3	10^4	10^3	10
4	10^3	10^2	10^3	10^3	10

Table 4

Bacterial population identified in monitoring campaign no.4

Sample no.	Bacteria number/exposed surface				
	Aerobic Bacteria	Anaerobic Bacteria	Acid Producing Bacteria	Sulfate Reducing Bacteria	Iron Oxidizing Bacteria
1	10^4	10^5	10^3	10^3	10^2
2	10^5	10^4	10^3	10^4	10
3	10^5	10^2	10^2	10^2	10
4	10^5	10^4	10^3	10^4	10

Table 5

Bacterial population identified in monitoring campaign no.5

Sample no.	Bacteria number/exposed surface				
	Aerobic Bacteria	Anaerobic Bacteria	Acid Producing Bacteria	Sulfate Reducing Bacteria	Iron Oxidizing Bacteria
1	10^2	10^2	10	10^2	10
2	10^2	10^3	10	10^3	10
3	10^2	10^2	10	10^3	10
4	10	10^2	10	10^2	10

The biofilm samples revealed, under microscope, sulfate reducing bacteria, acid producing bacteria and iron oxidizing bacteria characteristically shapes in all monitoring campaigns.

3.2. Characterization of the metal surface

Microscopic examination of the metal surface of disk coupons revealed different morphologies of corrosion attack, including terraced pitting specific to MIC. Due to the possible presence of other deposits on metal surface, as carbonates, sulfates, phosphates of alkaline earth metals, silica, corrosion products and suspended matter [13], MIC was not the only mechanism affecting the metal surface and there were distinguished several corrosion types. The most representative corroded surface morphologies in each monitoring campaign are presented in Fig. 1-5.

In monitoring campaign no.1, microscopic examination of the metal surface indicated general corrosion, the entire surface of the disk coupons being affected (Fig. 4).

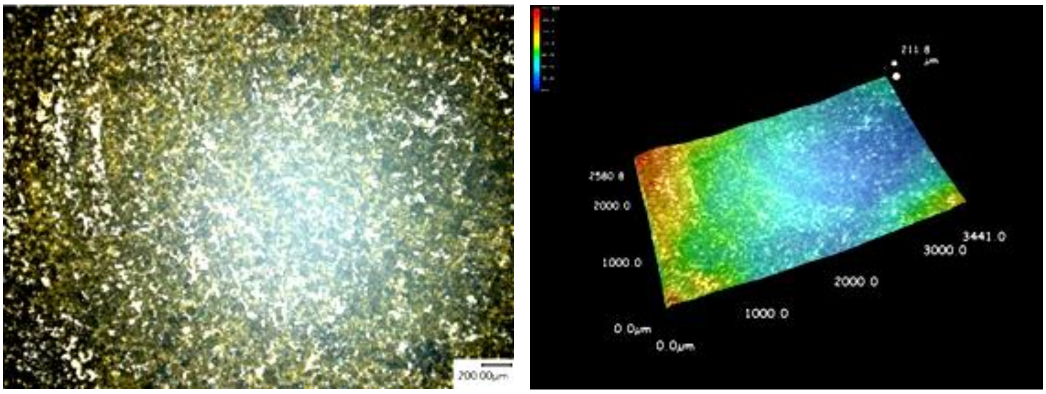

Fig. 4. 2D (left) and 3D (right) micrographs of the metal surface showing general corrosion in monitoring campaign no.1, 100X

In monitoring campaign no.2, microscopic examination of the metal surface revealed the terraced pitting (Fig. 5), a morphological characteristic for MIC, consisting in a corroded area in terraced form, surrounded by general corrosion or non-corroded areas. The terraced pitting is usually attributed to SRB activity [14].

In monitoring campaign no.3, microscopic examination of the metal surface revealed corrosion under-deposit (Fig. 6), only a part of the surface was corroded, as the deposits accumulated. This corrosion type cannot be attributed directly to MIC.

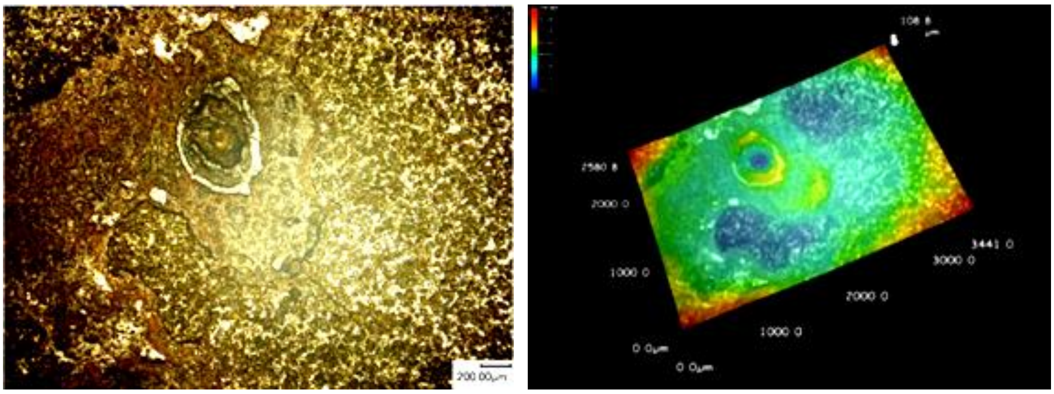

Fig. 5. 2D (left) and 3D (right) micrographs of the metal surface showing terraced pitting in monitoring campaign no.2, 100X

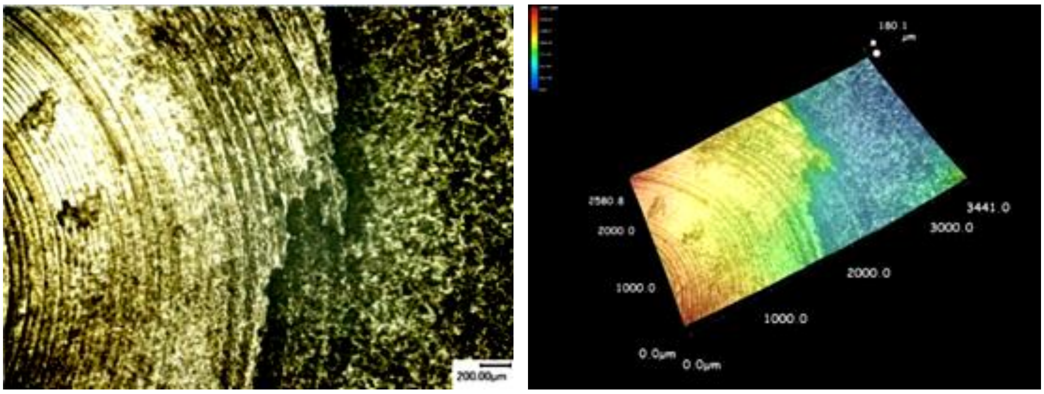

Fig. 6. 2D (left) and 3D (right) micrographs of the metal surface showing corrosion under-deposit in monitoring campaign no.3, 100X

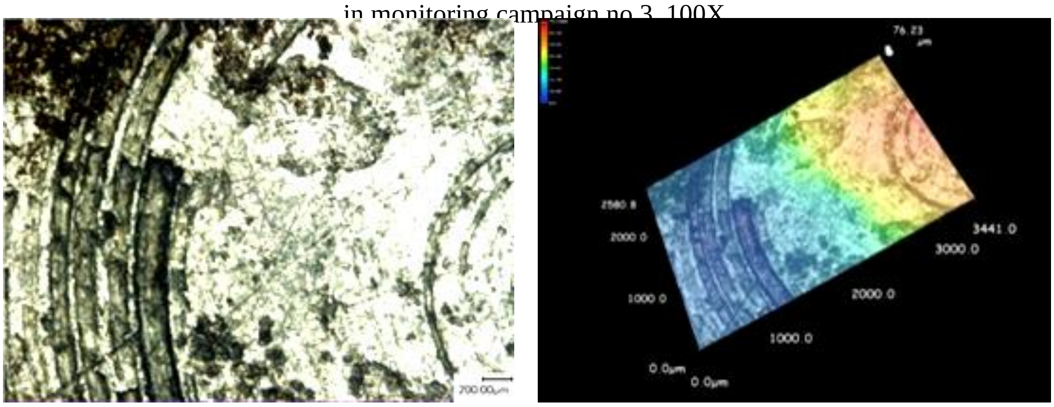

Fig. 7. 2D (left) and 3D (right) micrographs of the metal surface showing localized pitting and tunnelling effect in monitoring campaign no.4, 100X

In monitoring campaign no.4, microscopic examination of the metal surface revealed localized pitting and tunnelling effect (Fig. 7), another morphological characteristic for MIC, considered a sign of APB activity [14].

In monitoring campaign no.5, microscopic examination of the metal surface revealed low corrosion (Fig. 8), which can be correlated with reduced number of bacteria in biofilm.

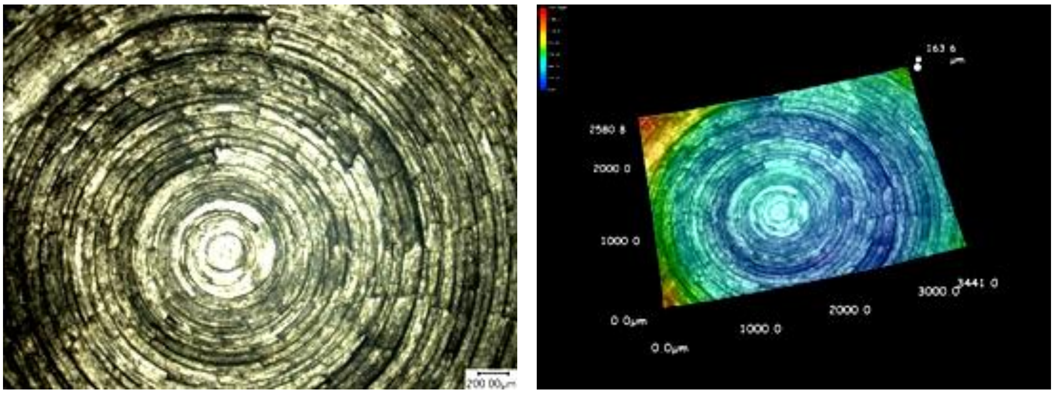

Fig. 8. 2D (left) and 3D (right) micrographs of the metal surface showing low corrosion in monitoring campaign no.5, 100X

3.3. Corrosion monitoring results

The results of corrosion monitoring of the injection water pipeline are presented in Table 6. The corrosion rate evolution was directly influenced by biocide treatment. After 4 months of treatment, it decreased from 1.050 mm/year to 0.042 mm/year. The differences in the exposure time do not influence the results because the corrosion rate is calculated considering the exposure time (see the mathematical formula).

Table 6

Corrosion rate and corrosion type

Monitoring campaign no.	Exposure period, month/s	Corrosion rate, mm/year	Corrosion type
1	1	no monitoring	
2	2	1.050	Severe
3	3	0.042	Moderate
4	2	0.829	Severe + MIC
5	1	missing coupons	

Also, the amount of scale in the pipeline decreased after 4 months of scale inhibitor treatment, leading to the decrease of injection water corrosivity.

The difference in corrosion rate values, considering the exposure time and the operating conditions, are:

- the value of 1.050, in a 2 months exposure period, was obtained at the beginning of treatment application, when the corrosivity of injection water was at high levels;

- the value of 0.042, in a 3 moths exposure period, was obtained after 4 months of biocide treatment and scale inhibitor treatment, which determined a significant decrease of corrosion intensity;
- the value of 0.829 mm/year, also in a 2 months exposure period, was influenced by changes in operating; in this period, the corrosion rate increased very much due to suspended solids entrained in water flow from the reservoir and due to acidizing treatment performed.

The corrosion type identified on the surface of corrosion coupons was severe and moderate, according to corrosion rate values. Also, the specific morphology of MIC, terraced pitting (Fig. 9), was observed in monitoring campaign no.4.

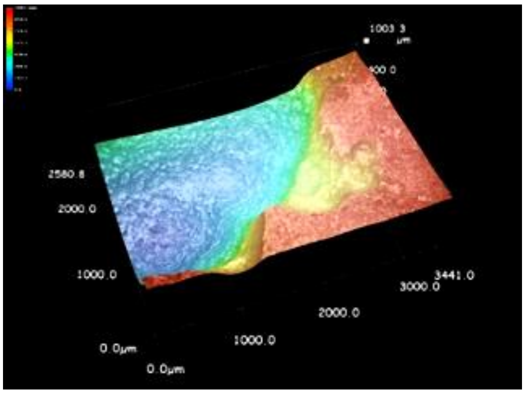

Fig. 9. 3D micrograph of the metal surface showing terraced pitting in monitoring campaign no.4, 100X

3.4. Biocide treatment evaluation

The biocide treatment efficiency could be evaluated by a short-term method, as device implementing and laboratory analysis of the biofilm and disk coupons. The efficiency of the treatment was demonstrated.

The general bacteria population progressively decreased during biocide treatment. The population of sulfate reducing bacteria decreased from a high number to a moderate population in the last monitoring campaign. Also, the number of acid producing bacteria in biofilm samples was low in the last monitoring campaign.

The morphologies specific of MIC on the surface of disk coupons were closely related to the diversity of bacterial population. In the case of a low bacterial activity, the effects of MIC were not identified by microscopic examination of the surface. After the number of bacteria increased, in monitoring campaign no.2, the appearance of terraced and localized shallow pitting, specific of MIC, was observed.

The efficiency of biocide treatment was also demonstrated by corrosion monitoring using corrosion coupons. There was a significant decrease of the corrosion rate, from 1.050 mm/year to 0.042 mm/year, after 6 months of treatment. The increase of the corrosion rate in monitoring campaign no.4 was caused by the higher concentration of suspended solids in the injection water and acidification of the oilfield.

4. Conclusions

This research demonstrates the efficiency of MIC control in the injection water pipeline, performed by device implementing in the field and laboratory analysis of the biofilm and corroded disk coupons. Analyzing the accumulated biofilm and examining the corrosive attack on the metal surface are very important steps in the complex process of MIC control. The results allowed to evaluate the efficiency of the biocide treatment in every monitoring campaign and to optimize the treatment, if necessary.

Bacteria causing MIC were confirmed in biofilm samples by microbiological analysis and microscopic examination. The localized corrosion morphology, resembling terraced pitting and tunneling effect observed on the disk coupons is a distinguished characteristic of MIC.

Characterization of the metal surface revealed different corrosion morphologies, caused by the complexity of the deposits which accompany the biofilm. Therefore, corrosion control program should continue, in addition to biocide treatment, with the scale inhibitor treatment, depending on the results of chemical analysis of the deposits.

More than that, in order to control the aggressiveness of the environment, filtration and separation of suspended particles are necessary along with corrosion inhibitor treatment, especially during acidifications.

For prevention of the growth of bacterial population and the associated problems, such as MIC appearance and, respectively, the formation of iron sulphide, it is necessary to continue the alternatively treatment with the 2 biocides and to optimize the treatment concentration.

By efficient MIC control program, the costs associated with microbiological activity can be significantly decreased due to clearly understanding of the unique behavior of MIC and recommendation of specific mitigation methods for every location where the phenomenon has been identified.

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