MICROBIOLOGICALLY INFLUENCED CORROSION ANALYSIS ON CARBON STEEL COUPONS

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The paper is focused on investigating the nature of the internal corrosion of a pipeline transporting residual injection water. The study was carried out using removable carbon steel disk coupons, for reproducing the effects of pipeline corrosion. Chemical composition, surface roughness and microstructure of the metal were determined and corresponded to a carbon steel used for pipelines manufacturing. Examination of corrosion morphology on metal surface was performed by analytical techniques, including optical microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM). The localized corrosion morphology (terraced pitting) observed on the disk coupons and the presence of bacteria associated with MIC in deposit samples confirmed the internal corrosion of the pipeline as microbiologically influenced corrosion.

Keywords: microbiologically influenced corrosion, SEM, AFM, terraced pitting

1. Introduction

Corrosion is a leading cause of pipeline failure and is a main component of the operating and maintenance costs of oil industry. Steel materials are corroded by not only pure physicochemical reactions, but also on metabolic activities of microorganisms. Corrosion of steel in this manner is termed as microbiologically influenced corrosion (MIC) [1].

Pipelines transporting water or aqueous fluids such as brine, waste water or produced water may experience MIC and/or other types of internal corrosion at locations throughout the pipeline system that are difficult to predict [2].

MIC mechanism can be explained by different ways, but the most used manner is cathodic depolarization theory, which is based on the hydrogen consumption activity of sulfate reducing bacteria, promoting iron dissolution [3].

MIC is accompanied by the formation of slimes or deposits, beneath which anaerobic conditions prevail. Hence it is possible that a highly aerobic environment may nevertheless encourage the growth of corrosion-causing anaerobic microorganisms.

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The appearance of the cleaned metal surface can also provide a clue to the nature of the cause of corrosion. Terraced pitting is indicative of bacterial attack, especially of sulfate reducing bacteria. Uniform corrosion could suggest that the cause may be due to acid production by microorganisms, or may not be biological at all, therefore, in order to confirm MIC, it is essential to document the presence of microorganisms [4].

The purpose of the paper is to confirm the nature of the corrosion, suspected as microbiologically influenced corrosion, identified on internal surface of a pipeline transporting residual injection water. Investigation of corrosion morphology on removable carbon steel disk coupons was conducted using analytical techniques, including optical microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM), along with microbiological analysis of the deposit.

2. Experimental part

2.1. Sampling device

The study was carried out using an in-house manufactured device installed as side stream of a pipeline transporting residual injection water, located in a Romanian oilfield. The device allowed the accumulation of deposit on disk coupons and indicated the effect of corrosion attack by examining the metal surface. The installation point of the device is presented in fig. 1.

Fig. 1. Installation point of the device

The device had removable carbon steel disk coupons exposed internally, with similar metallurgy as the pipeline and electrically isolated to prevent galvanic corrosion. The disk coupons in "6 o'clock" position were considered, being the most representative to observe corrosion effect on metal surface. The device was exposed 6 months and transported, maintaining the same anaerobic conditions, from in-situ location to laboratory for corrosion analysis on disk coupons.

2.2. Disk coupons preparation

Before mounting into the device, the disk coupons were sterilized in the laboratory to avoid pre-contamination. After the exposure period, the disk coupons were cleaned using protective gloves with a detergent, rinsed with water, immersed into acetone and dried under air jet in order to remove the accumulated deposit on the surface [2].

2.3. Deposit analysis

The deposit was analyzed by the most probable number (MPN) method [5] in order to determine the presence of biofilm containing bacteria.

2.4. Metal characterization

The chemical composition of the metal was determined by spectrochemical method [6]. The surface roughness was measured for each disk coupon [7]. The metallographic analysis was performed using a stereomicroscope type OLYMPUS SZX, equipped with soft QuickMicroPhoto 2.2, an optical microscope type Reichert and a scanning electron microscope type Philips.

2.5. Examination of corrosion morphology

The examination of corrosion morphology on metal surface was performed using different analytical techniques including optical microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM).

3. Results and discussion

3.1. Deposit analysis

Microbiological analysis of the deposit confirmed the presence of bacteria associated with MIC. A diversity of bacterial communities was observed, mostly population of sulfate reducing bacteria (SRB) and acid producing bacteria (APB).

3.2. Metal characterization

The disk coupons had similar metallurgy as the pipeline for reproducing the effects of pipeline corrosion. Chemical composition, surface roughness and microstructure of the analyzed metal corresponded to a non-alloyed carbon steel used for pipelines manufacturing.

The chemical composition of the metal is presented in Table 1.

The chemical composition corresponds to non - alloyed carbon steel, type AISI 1035.

Table 1

Chemical composition of disk coupon metal

Chemical composition [%]									
C	Si	Mn	S	P	Cu	Ni	Cr	Mo	Al
0.39	0.29	0.59	0.024	0.007	0.16	0.06	0.08	0.01	0.02

The measurements of surface roughness are presented in Table 2.

Table 2

Surface roughness of the disk coupons

Disk coupon	Roughness, µm
1	3.71
2	3.39
3	3.61
4	3.76
average	3.62

The metallographic examination of the surface revealed non-metallic inclusions of oxide type according to ASTM E45 [8] and homogeneous structure consisting in ferrite and pearlite, specific to a carbon steel.

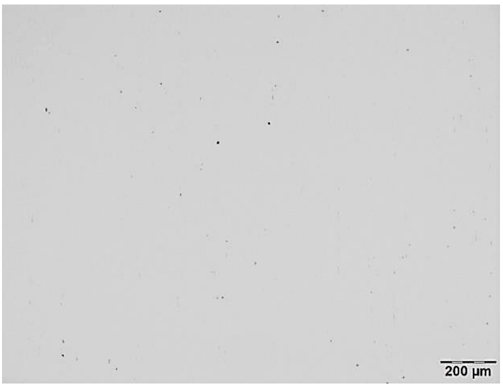

Fig. 2. Structural analysis of the non-attacked sample of the investigated carbon steel, 100X

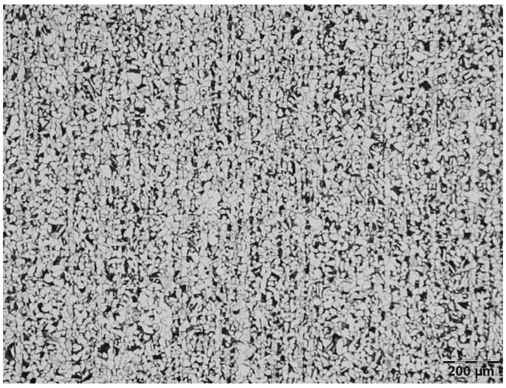

Fig. 3. Microstructure of the investigated carbon steel (2% nital attack, 100X)

Microscopic examination on disk coupons surface revealed MIC resembling morphology. The differences between unexposed surface and corroded surface exposed in “6 o’clock” position are presented in the following micrographs.

3.3.1. 2D and 3D measurements

Microscopic examination of the metal surface indicated localized corrosion (terraced pitting) specific to MIC on disk coupons in “6 o’clock” position. In figure 4 is illustrated the aspect of the surface before (a) and after (b) exposure as is given under the stereomicroscope. As one can see the corrosion appears on all surface with material slices of relatively uniform and oxidized appearance.

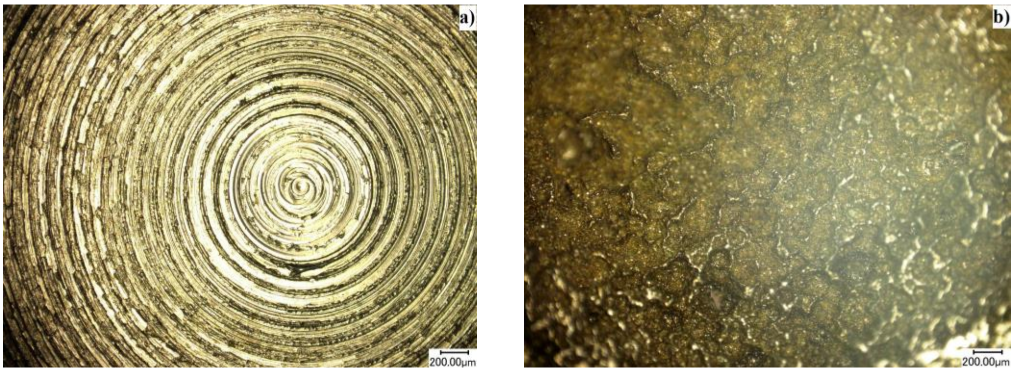

Fig. 4. Stereomicroscope analysis (2D micrographs) of the investigated carbon steel:
a) unexposed surface, b) corroded surface

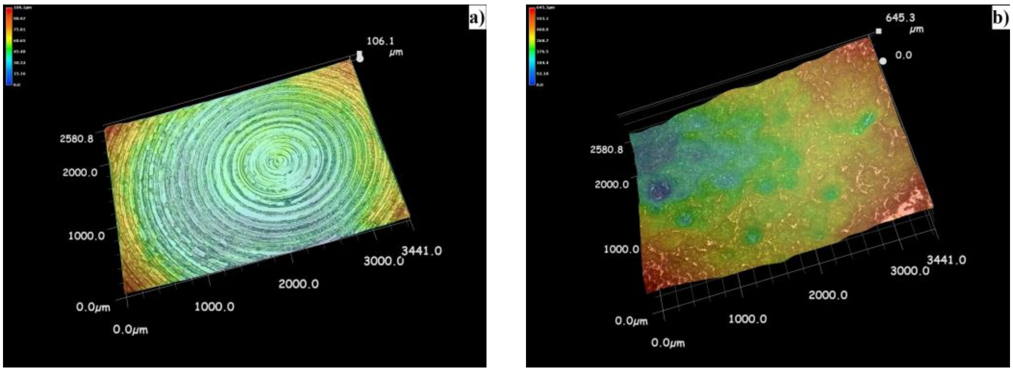

Fig. 5. 3D micrographs of the investigated carbon steel, 100X:
a) unexposed surface, b) corroded surface

Isometric representation of surface topography given in figure 5 put in evidence the morphological details. In unexposed surface (fig.5a), many scratches in circle shape are shown in comparison with corroded surface (fig.5b), where in the selected area for analysis, there is a big contrast between center and edge due to corrosion phenomena.

3.3.2. Scanning electron microscopy

The images from the SEM are given in figure 6, where one can see the great difference between the two fractured surfaces. In unexposed surface, no scratches can be seen (fig. 6a), but in corroded surface (fig. 6b), spherical unevenness due to microbiological influenced corrosion can be observed.

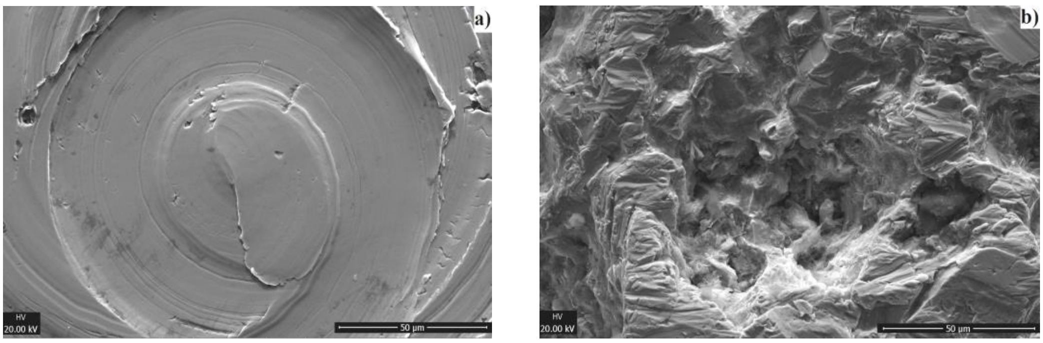

Fig. 6. Scanning electron micrographs of the investigated carbon steel surface, 2.500X:
a) unexposed surface, b) corroded surface

3.3.3. Atomic force microscopy

The analysis made by atomic force microscopy put in evidence an uneven appearance, with great unevenness, generated by the microbiological influenced corrosion phenomenon. If at the non-exposed surface the leveling reaches up to 1.8 μm, at the corroded surface it increases to 2.5μm.

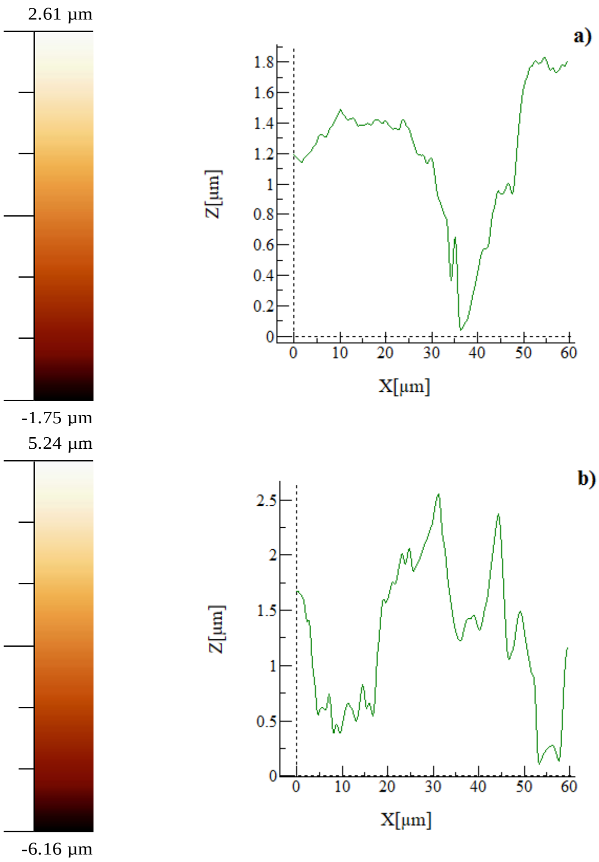

Fig. 7. AFM topographic micrographs and surface height profile of disk coupon:
a) unexposed surface, b) corroded surface

6. Conclusions

The corrosion identified on internal surface of a pipeline transporting residual injection water was confirmed as microbiologically influenced corrosion, by investigations on corrosion morphology, integrated with microbiological results, to distinguish MIC from other corrosion mechanisms.

All bacteria responsible for MIC were determined in deposit sample, mostly population of SRB and APB.

The localized corrosion morphology (terraced pitting) observed on the disk coupons is typical of MIC, attributable to SRB and APB activity. Features of corroded metal surface, resembling bacteria attack, were also observed using Scanning Electron Microscopy and Atomic Force Microscopy.

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R E F E R E N C E S

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