

The Effect of Bacteria and Soil Moisture Content on External Corrosion of Buried Pipelines

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ABSTRACT

One of the major causes of failures in buried pipelines has been identified as microbiologically influenced corrosion (MIC). Globally, the contribution of MIC in total number of buried pipeline failures is estimated to be between 10% to 70%. This research investigated simultaneously two of the most influential factors in corrosion of buried pipelines: bacteria and soil moisture content. All test parameters were chosen based on actual field conditions to have more reliable and attributable results. Sulfate reducing bacteria (SRB) strain, *Desulfovibrio desulfuricans*, was used for the experiments. Weight loss experiments were carried out using API 5L X65 carbon steel in No SRB and With SRB conditions at three different soil moisture contents in a sandy soil. Results showed that an increase in the soil moisture content decreased the corrosion rate. The presence of SRB in soil, although increased the rate of corrosion and aggravated pitting corrosion at low moisture contents, decreased the corrosion rate at higher moisture contents. At low moisture contents, two layers of corrosion products and at high moisture contents, one layer of corrosion products formed on the surface of specimens. X-ray diffraction (XRD) analysis was conducted to analyze the corrosion products.

Keywords: Pipelines, carbon steel, soil moisture content, sulfate reducing bacteria, soil corrosion, external corrosion

INTRODUCTION

Buried mild steel pipelines are protected against external corrosion by the simultaneous application of protective coatings and cathodic protection^{1,2}. Despite the effectiveness of these protective measures, in the presence of coating flaws, which are inevitable, coating adhesion to the steel surface decreases over time and cathodic protection current may become insufficient in these areas; thus, the bare steel will be exposed to the corrosive environment of soil^{1,3}.

One of the major causes of buried pipeline failures has been identified as microbiologically influenced corrosion (MIC)¹. Estimations about the contribution of MIC in total number of corrosion incidents related to buried pipelines vary broadly from 10% to 70%⁴⁻⁹. It is believed that sulfate reducing bacteria (SRB) are among the most problematic group of microorganisms involved in MIC^{3,10-13}.

Most studies about the role of SRB in external corrosion of buried pipelines showed that SRB aggravated corrosion^{4,12,14–16}. Despite the detrimental role considered for SRB, some researchers have recently found that sulfide films caused by SRB activity at a metal substrate, had protective effects and slowed down the corrosion rate^{12,14,17–19}.

Although plenty of studies have been performed on the effects of SRB on corrosion of steels, most of them were in sea water environments or simulated soil solutions, while few of them were carried out in actual soil environments. Therefore, no consistent and conclusive opinion about the effects of SRB on corrosion of steels in soil has been made so far. In the present study, the role of SRB in corrosion of a buried pipeline steel will be investigated, using soil of Kharg Island, Iran's primary export port for oil, where kilometers of buried gas and oil pipelines exist²⁰. Weight loss measurement, stereo-microscopy and X-ray diffraction (XRD) were employed in the experiments.

EXPERIMENTAL PROCEDURE

In this paper, the simultaneous effects of SRB and soil moisture content on corrosion behavior of a buried pipeline steel are explored. All test parameters were chosen based on real field conditions to have more reliable and attributable results.

Steel specimens

API 5L X65 carbon steel commonly used for modern oil and gas pipelines was chosen as the specimen material. Table 1 shows the nominal composition of API 5L X65 steel used for the experiments. The X65 steel was annealed with a ferritic pearlitic microstructure (80% ferrite, 20% perlite) and a grain size of 8 according to ASTM E112.

Table 1: Chemical composition of the experimental carbon steel, API 5L X65 (in wt.%).

Al	C	Ca	Cr	Cu	Mn	Mo	Nb	Ni	P	S	Si	Ti	V	Fe
0.039	0.07	<0.002	0.164	0.016	1.515	0.003	0.043	0.012	0.01	0.002	0.22	0.013	0.042	Balance

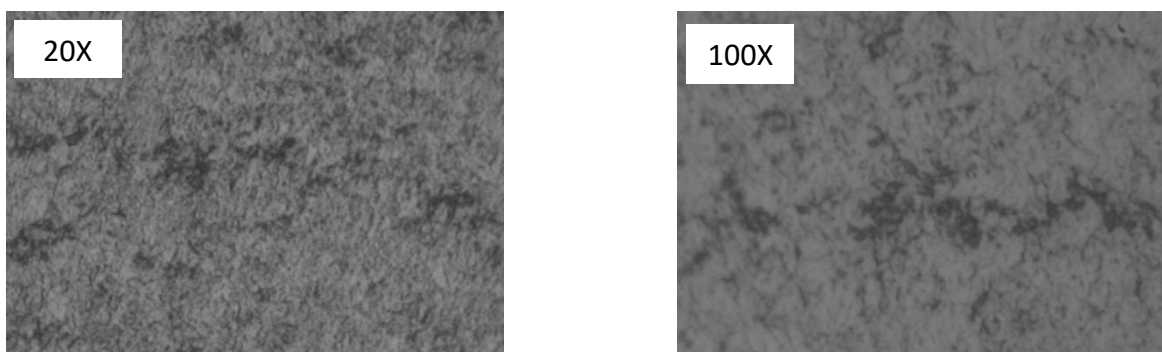


Figure 1. Metallography images of the API X65 5L carbon steel used in the experiments.

Experimental soil

Two main soil formations exist on Kharg Island: Aghajari and Limestone (Figure 2). It is reported that the average thickness of Limestone formation (formation A in Figure 2) in Kharg Island is about 2 m²¹. Considering that the average burial depth for oil and gas pipelines is 1 m²², the limestone formation was used as the experimental soil. Approximately, 70 kg of Limestone soil was collected for the experiments.

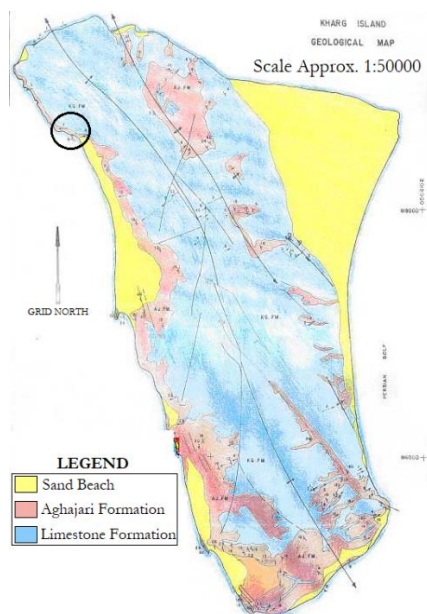


Figure 2. On the left, the geological map of Kharg Island. The location where the experimental soil (Limestone) was collected is marked by a circle on the map. On the right, a picture of extraction site that shows Limestone (A) and Aghajari (B) formations.

Soil physicochemical properties

The chemical analysis of the soil was conducted using wet chemistry (BS-1377-3 standard) and X-ray diffraction (XRD). The results are shown in Table 2 and Figure 3. The main element in the soil was calcium and the main phases were calcium carbonate, aragonite, and quartz.

Table 2. Chemical analysis of the experimental Limestone soil.

Element/ion (wt. %)	pH	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	SO ₃ ²⁻ *	SO ₄ ²⁻	Cl ⁻	CO ₃ ²⁻	HCO ₃ ⁻	Organic content	TDS*
Limestone	7.42	0.210	0.022	0.391	32.421	1.03	trace	0.026	0.007	0.025	0.39	0.56

*Total dissolved salt

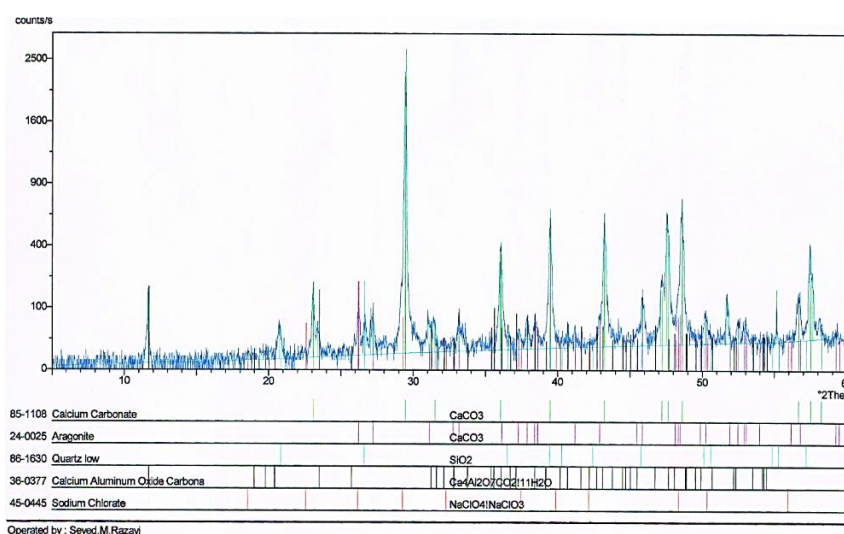


Figure 3. XRD spectrum and phase analysis of the Limestone soil used for the experiments.

The particle size distribution test was carried out according to ASTM standard D422-02. Both sieving and sedimentation processes were used to have a complete particle size distribution of the soil. Table 3 shows the results. According to the soil texture classification triangle²³, the Limestone soil is classified into sand category.

Table 3. Particle size distribution analysis of Limestone soil used for the weight loss corrosion measurements.

Soil separate	Soil separate dimension range (ASTM D422-02)	Weight percentage in (wt.%)
Gravel	> 4.75 mm	6.29
Sand	0.047 mm to 4.75 mm	89.20
Silt	0.005 mm to 0.047 mm	2.76
Clay	< 0.005 mm	1.75

The pH of soil was measured 7.42 in a 1:1 v/v mixture of dried soil and distilled water²⁴. Soil resistivity (ρ) in Ohm.cm was measured according to the Wenner four-pin method (ASTM G57-95), using Equation (1). A simple schematic of the method and a picture of the apparatus used for measuring soil resistivity are shown in Figure 4. The distance between the pins (a) was set at 4 cm. For soil resistivity measurements, an alternating current (I) was applied between the outer pins (C1 and C2) and the corresponding voltage drop (V) was measured between the inner pins (P1 and P2). R in Ohm was simply calculated using the Ohm's law ($V = IR$). For each moisture content, 5 measurements were carried out at 5 currents (2, 4, 6, 8, and 10 mA) and soil resistivity was averaged over these 5 points.

$$\rho = 2\pi aR \quad (1)$$

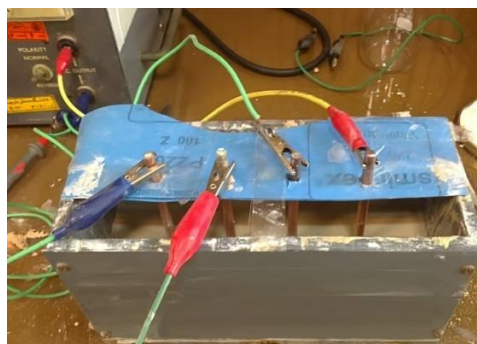
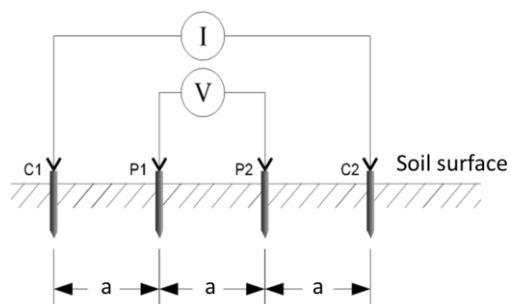


Figure 4. The schematic of the Wenner Four pins method used for soil resistivity measurements (left). The experimental apparatus used to measure soil resistivity (right).

Figure 5A shows soil resistivity measured at three moisture contents. Soil resistivity decreased with increasing moisture contents. This is because water facilitates the transfer of charges in soil environments, and thereby decreases soil resistivity. Soil resistivity is usually used as a tool to determine corrosiveness of soil. Based on Figure 5B, the experimental soil is considered as a highly corrosive soil.

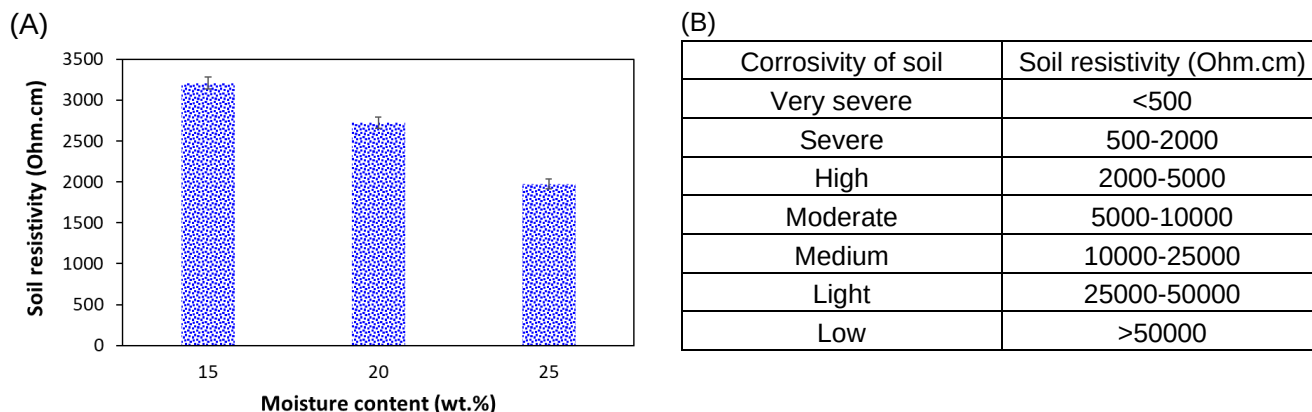


Figure 5. (A) The measured resistivity of Limestone soil vs. moisture content. The error bars represent the minimum and maximum values obtained in repeated experiments (5 repeats). (B) Soil corrosivity categories for buried mild steel based on soil resistivity, taken from “ASTM corrosion Tests and Standards Application and Interpretation 2005”.

Soil moisture content

During the year in Kharg Island, the soil moisture content at a depth of 1 m varies regularly between approximately 15 wt.% to 25 wt.%* (Figure 6). Thus, experiments were carried out at three soil moisture contents of 15, 20, and 25 wt.% to cover the range of soil moistures seen in Kharg Island.

To achieve the selected moisture contents, first, all the large lumps/clods were removed from the collected soil. Then, soil was dried by heating it at 105°C for 48 hr²⁵. Finally, the experimental moisture contents were adjusted by adding sterilized DI water to the dried soil. The adjustment of soil moisture contents was conducted after soil sterilization, which will be explained in the next section.

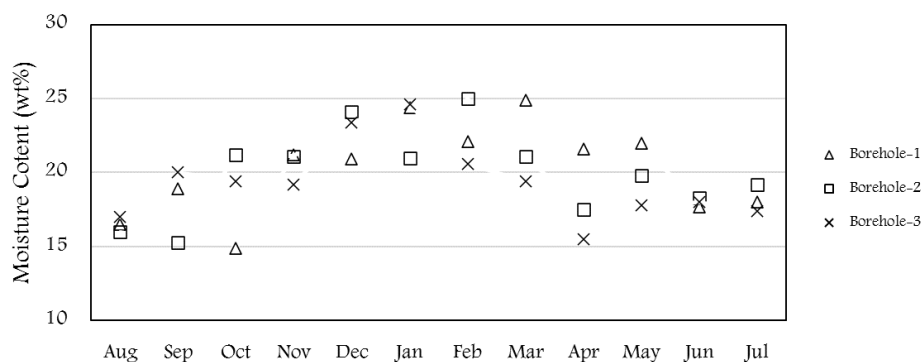


Figure 6. Variation in the soil moisture content at the depth of 100 cm in Kharg Island. Reproduced with permission²¹.

Soil sterilization

The dried soil was sterilized twice by autoclaving at 121°C and a steam pressure of 15 psi for 20 min in metallic baking pans covered with aluminum foil. One sterilization cycle was not enough to kill the bacteria and sterilize the soil. Figure 7 shows two similar soil samples, one was sterilized for one cycle (Figure 7 A) and the other was sterilized twice (Figure 7 B). The former turned to black after four days, which was an indication of sulfide production, and thereby SRB presence.

* Soil moisture content (wt.%) = $100 \times \text{mass of dried soil} / (\text{mass of dried soil} + \text{mass of added water})$