



Effect of temperature and fluid speed on the corrosion behavior of carbon steel pipeline in Qatari oilfield produced water



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ABSTRACT

Metals integrity, such as carbon steel used in pipeline network can be seriously damaged by produced water causing serious corrosion problems. This can result in significant threats to safe operation of the oilfield facilities and leads to considerable economic losses. In this study, the effect of produced water from the North oilfield of Ras Laffan in Qatar on corrosion and scaling of carbon steel is investigated using electrochemical methods. The specimen rotation speed ranged from 0 to 2 m/s and temperature between 20 and 60 °C were used as test parameters for the study. X-ray power diffractometer (XRD) and scanning electron microscopy (SEM) techniques were employed in the analysis of the corroded steel samples. It was found that the corrosion rate increased with increasing temperature and specimen rotation speed. These results also showed that the steel reacted with the corrosive ions at the early stage of its exposure to the produced water leading to the formation of corrosion products on the steel surface in which CaCO₃ scale layer were deposited on the surface of the specimen as loose products due to the presence of large amounts of Ca²⁺ and HCO₃⁻ ions contained in the Ras Laffan oilfield produced water. More so, pitting and cracks were observed on the steel surface which increased as the temperature and specimen rotation speeds were increased, suggesting localized corrosion mechanism.

1. Introduction

Leakage in the oilfield pipelines can affect the normal production rate, cause enormous economic loss, and even results in huge security risk [1–3]. Oilfield produced-water considered as industrial wastewater is formed during petroleum exploration and its utilization processes. Some regions have water deficiency [4,5] and continuous usage of clean water and increased industrial water waste in these regions may result in complete water shortage. Suspended solid particles found in oilfield water can influence the corrosion behavior of pipeline and marine structures. More so, the presence of polar compounds, such as asphaltenes, surfactants and polymer can block the wellbore valves as well as accumulate in the pipelines. The presence of crystallized wax, clays and scales found at the oil/water interface are known to produce unwanted stable emulsions that generate operational corrosion problems. Furthermore, crude oil contains some gases which are naturally corrosive [6]. Produced-waters are enriched with abundant corrosive substrates [7,8], which can affect the integrity of containing pipe materials resulting in huge economic losses. The influence of produced-water on corrosion behavior of pipelines and equipment used in the

petroleum industry has become an issue of international interest [9–12].

Zhang et al. [13] studied the corrosion behavior of X65 steel in simulated oilfield water at different temperatures, acetic acid concentration and carbon dioxide using electrochemical and characterization techniques. The result showed increase in the corrosion rate with FeCO₃ formation as the test parameters were increased. In as much as addition of acetic acid could enhance hydrogen depolarization, further addition of the acid resulted in the removal of FeCO₃ layer formed on the steel surface. In a similar study, Migahed et al. [12] investigated the impact of inhibitor on the corrosion behavior of X65 steel in CO₂ saturated oilfield produced water. The result revealed that the inhibition ability of the selected inhibitor influenced both the cathodic and anodic reactions. Other researchers [14,15] have investigated the inhibition effect of some particles found in produced water. However, there has been little research on the effects of “real” produced-water on corrosion of the pipeline used in different oilfields and regions [16,17]. Furthermore, many parameters, such as solid particles found in oilfield, crude oil, oxygen, temperature and composition etc. have been reported to be influential in the corrosion process and strongly influence the

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corrosion of steels [18–20]. The need to investigate the influence of produced from the North oilfield of Ras Laffan in Qatar on the corrosion behavior of carbon steel (CS 1018) which is one of the commonly used steel material in petroleum industry becomes necessary [21–24].

This study focuses on the electrochemical examination of carbon steel (1018) behavior in produced-water collected from the North oilfield of Ras Laffan in Qatar at different temperatures ranged from 20 to 60 °C and specimen rotation speeds between 0 and 2 m/s. Potentiodynamic polarization and Electrochemical Impedance Spectroscopy were used to investigate the electrochemical behavior. The corroded surfaces were characterized using visual camera, scanning electron microscopy (SEM) and X-Ray Diffraction (XRD) to study their compositional and surface features. The results reported here concerning the influence of “real” produced-water on the corrosion behavior of 1018 carbon steel will be useful and help the research community and the industry in understanding its corrosion behavior in oil/water environment.

2. Experimental

2.1. Material and solution

Carbon steel (CS1018) of a 10 mm diameter mounted in a resin sample holder with an exposed area of approximately 0.7854 cm² was used as the working electrode in all the corrosion experiments.

The chemical composition of the specimen is given in Table 1.

In order to understand the chemical composition of the oilfield water used in the experiments, the produced water sample was collected from the water treatment plant in Ras Laffan oil and gas oilfield north of Qatar. The properties of produced water are listed in Table 2 with average pH value of 7.8.

2.2. Experimental set up

A conventional three-electrode electrochemical glass cell shown in Fig. 1 with a 125 ml corrosion cell supplied by GAMRY was used for corrosion tests. A reference electrode made of silver/silver chloride (Ag/AgCl) filled with 3 M KCl solution and placed inside a Luggin capillary filled with the test solution were used for electrochemical measurements. A graphite counter electrode of 6 mm in diameter was also used in the tests as shown in Fig. 1.

A condenser was used to reflux any evaporated solution and assuring a constant solution level when high temperatures were applied. The corrosion cell temperature was controlled using a water circulator (HAAKE A 25/Thermo digital system) connected to the cell jacket and the temperature inside the cell was monitored with a digital thermometer. The cell was mounted on a magnetic stirring plate to ensure proper mixing of the solution. The stirring speed was kept at its minimal value. All electrochemical experiments were performed on Gamry Ref 600 potentiostat ($\pm 0.2\%$ accuracy on potential and current readings) using the General Purpose Electro-chemical Software (GPES version 4.9.007) to control the instrument and record corrosion data. Echem Analyst™ Software was used to analyze the data [25,26].

2.3. Electrochemical measurement

The electrochemical measurements were performed using Gamry Ref 600 potentiostat. The rotating disk electrode (RDE) was abraded with a series of grit papers (220, 400, 600, 1000 and 2000) and

Table 1
Carbon steel specimen chemical composition.

Co (%)	Ni (%)	Cu (%)	Zr (%)	Cr (%)	Fe (%)
0.96	0.55	0.07	0.05	0.85	97.52

subsequently cleaned in acetone, alcohol and distilled water before being dried. A deoxygenating process was carried out using nitrogen for 30 min prior to filling the electrochemical cell with proper volume of the produced water. The open circuit potential (OCP) of the cells were measured before reaching stability (defined as OCP < 5 mV/20 min). The Electrochemical Impedance Spectroscopy (EIS) measurements were carried out at OCP over the frequencies from 0.001 Hz to 100 kHz with application of 10 mV amplitude sinusoidal voltage as disturbance signal. The polarization curves (Tafel plots) were performed at a potential range from ± 250 mV versus open circuit potential (OCP) with a scan rate of 0.167 mV/s. The electrochemical measurements were performed at temperatures varying from 20 to 60 °C in increment of 10 °C and different rotation speeds of 0, 0.52, 1.1, 2.1 and 4.2 m/s corresponding to 0, 500, 1000, 2000 and 4000 (RPM) respectively as shown in Table 3.

The conversion of rotation speeds to revolution per minutes was carried out using the method detailed elsewhere [27]. Each test was repeated three times for reproducibility.

2.4. Morphology observation and composition analysis

The corrosion morphologies before and after removing corrosion products, as well as the cross-section morphologies, were characterized using scanning electron microscope (SEM) (JCM-6000-Jeol) with the beam voltage at 25 kV. Corrosion products on the corroded specimen were analyzed using Rigaku Miniflex II Desktop X-ray Diffractometer (XRD). A high resolution camera was used for visual inspection of the corroded specimens.

3. Results and discussion

3.1. Electrochemical measurements

3.1.1. Effect of temperature

To investigate the effect of the temperature on the corrosion behavior of the metal samples, five different temperatures were chosen (20, 30, 40, 50 and 60 °C). Fig. 2 shows the Tafel and corrosion rate plots for the solution at zero flowrate (0 rpm). It can be seen that the Tafel curves shifted to the right with increase in the temperature. This behavior can be attributed to current density impact on corrosion when the temperature was increased from 20 to 60 °C (Table 4) and can also be ascribed to increase in metal dissolutions and oxidation-reduction reaction as the temperature was increased.

Table 4 clearly shows that corrosion rate increased with increase in the temperature. Fig. 3 shows the Nyquist diagram with fitting results at 0 rpm and at different temperatures.

The spectrum at 20 °C revealed the presence of two time constants of an inductive loop and a capacitive loop which is in agreement with results reported by Yongxin et al. [28]. The inductive loop is usually related to adsorbed species [29], and the capacitive loop indicated that the sample surface was partially covered with corrosion scale. Our result is in good agreement with the result reported by Zhang et al. [15]. The EIS diagrams measured at 30 and 40 °C appeared identical. Similarly, the same remark is observed for EIS diagrams measured at 50 and 60 °C with the capacitive loop diameter decreasing as the temperature was increased.

The EIS data measured between 20 and 60 °C are fitted by the electrochemical equivalent circuit shown in Fig. 4. In the diagram R_s represents the electrolyte solution resistance, R_p and CPE_1 represent a resistance and a capacitance of the film made of the corrosion products respectively. While R_{ct} represent a charge transfer resistance, CPE_2 is a double layer capacitance.

The parameters deduced from the EIS simulation analysis are shown in Table 5. All the values were obtained using the Gamry Echem Analyst Software [30].

Fig. 3 and Table 5 shows that R_{ct} decreases with increased

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