Corrosion Science 77 (2013) 334–341

Contents lists available at ScienceDirect

Corrosion Science

journal homepage: www.elsevier.com/locate/corsci

A study of flow accelerated corrosion at elbow of carbon steel pipeline by array electrode and computational fluid dynamics simulation

G.A. Zhang *, L. Zeng, H.L. Huang, X.P. Guo

School of Chemistry and Chemical Engineering, Huazhong University of Science and Technology, Hubei Key Laboratory of Materials Chemistry and Service Failure, Wuhan 430074, China

A R T I C L E I N F O

Article history:
Received 10 April 2013
Accepted 26 August 2013
Available online 3 September 2013

Keywords:
A. Carbon steel
B. EIS
B. SEM
B. Raman spectroscopy
C. Acid corrosion

A B S T R A C T

A novel method by combining array electrode technique with computational fluid dynamics (CFD) simulation was proposed to determine the correlation between the corrosion behavior at the elbow of pipeline and the hydrodynamics of fluid flow. It is demonstrated that the distribution of the measured corrosion rates is in good accordance with the distributions of flow velocity and shear stress at the elbow. The corrosion rates at the inner wall of elbow are higher than those at the outer wall of elbow. The maximum corrosion rate appears at innermost side while the minimum corrosion rate at outermost side of the elbow.

1. Introduction

In oil and gas industry, the corrosion of pipelines under flow condition usually poses great threat to carbon steel pipelines [1,2]. It would cause pipeline failure during the oil and gas transportation and massive costs are directed annually to alleviating and managing the corrosion of pipelines [3–5]. Flow accelerated corrosion (FAC), also sometimes referred to erosion–corrosion (E–C) when there are solid particles in the solution, has been identified destructive in the corrosion of pipelines [6,7], especially in CO_2 environment [8–10], since the flow conditions have significant effect on the mass transfer process and the removal of corrosion products on electrode surface.

Presently, there are usually three methods for FAC study, i.e., rotating disk electrode (RDE) or rotating cylinder electrode (RCE) technique [11–16], impingement jet system [17–25] and loop system [26,27]. RDE or RCE technique, in which the electrode rotates in static solution, is relatively simple and suitable for the studies on mass transfer process and kinetics. Furthermore, this method can be used for the case with high concentration of solid particles in the solution. An impingement jet system is implemented by the impingement of flow fluid from a nozzle to electrode surface. The impingement of flow fluid can also be implemented at different impact angles. For example, the previous work on FAC of carbon steel array electrodes by using an impingement jet system [8] revealed that the corrosion rates of electrodes are directly related to the distributions of flow velocity and shear stress on the electrode surfaces. However, both RDE or RCE technique and impingement jet system cannot completely reflect the flow pattern in a pipeline. To simulate the flow pattern in a pipeline more realistically, loop system should be applied.

In oil and gas transportation, elbow is an important part of most practical pipe configurations. However, the flow pattern in a 90° elbow is subject to great changes in flow direction and flow velocity [28], thus leading to significant difference in corrosion behavior at different locations of elbow. Due to the sudden change in flow pattern, the wall thinning by FAC is exacerbated at elbow. Therefore, FAC at elbow is rather serious among the damages of pipelines [29,30]. Apparently, there should be correlation between the corrosion behavior at different locations of elbow and the flow patterns. Array electrode technique, a configuration of multi-electrodes system, can be used for determining the heterogeneous electrochemical corrosion difference at different locations of elbow.

In this work, a novel method was proposed to study the hydrodynamic effects of flow fluid on the FAC in a 90° elbow by combining array electrode technique with computational fluid dynamics (CFD) simulation. The specific objectives of this work are to numerically simulate and characterize the flow patterns within a pipeline elbow, and to determine the correlation between the corrosion behavior at a pipeline elbow and the distributions of flow velocity and shear stress.

* Corresponding author. Tel.: +86 27 87559068; fax: +86 27 87543632.
E-mail address: zhangguoan@gmail.com (G.A. Zhang).

0010-938X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.corsci.2013.08.022

2. Experimental

2.1. Electrodes and solution

To study the corrosion behavior at elbow, array electrodes, which were made up of X65 pipeline steel with an exposed area of 3 mm × 4 mm, were used in this experiment. Copper wire was welded to each array electrode to ensure electrical connection for electrochemical measurements. Before FAC test, the surfaces of array electrodes were ground with 800 silicon carbide paper, and then rinsed with deionized water, cleaned with alcohol.

The test solution is prepared according to the composition of formation water drawn out from an oil field. It contains 17.24 g/L NaCl, 0.54 g/L KCl, 0.43 g/L $CaCl_2$, 0.37 g/L Na_2SO_4, 0.50 g/L $MgCl_2$ $6H_2O$, 3.98 g/L $NaHCO_3$, which was made up from analytical grade reagents and deionized water. Prior to FAC test, the solution was deaerated by purging CO_2 (99.95%) for 24 h. After saturated with CO_2, the pH of solution is 6.15. CO_2 gas-purging was maintained to ensure an entire saturation throughout the test.

2.2. Loop system for FAC test

A circulating loop system was used for FAC test, as shown in Fig. 1(a). It consisted of pipes, a centrifugal pump, a reservoir, a pressure gage, a flow meter and array electrode test section. The solution was supplied from a 40 L reservoir and circulated through the centrifugal pump. The flow velocity was controlled by controlling the pump rotational speed using a speed controller. The flow velocity in this study is 3.4 m/s, which was measured by using a flow meter. The loop system was made of plexiglass tube with an inner diameter of 50 mm. The diameter of loop and the flow velocity are selected according to the operating conditions in the oil field. After pretreatment, array electrodes were mounted into the elbow test section with the same spacing distance in flow direction. The exposed surfaces of array electrodes were in accordance with the internal surface of pipelines, as shown in Figs. 1(b) and (c). (d) shows the photograph of test section, with 50 specimens at elbow, 6 specimens in the straight pipe upstream of elbow and 12 specimens in the straight pipe downstream of elbow.

2.3. Electrochemical measurements

An electrochemical test system was used for in situ electrochemical measurements during FAC test. A three-electrode electrochemical cell was constructed in test section with the array electrodes as working electrodes (WE), a platinum plate as counter electrode and a saturated calomel electrode (SCE) as reference electrode. To determine the corrosion rate (corrosion current density) of each array electrode, electrochemical impedance spectroscopy (EIS) measurements were performed at open circuit potential (OCP) with a sinusoidal alternating amplitude of 10 mV and the frequency from 10,000 Hz to 0.1 Hz. Then, the corrosion current

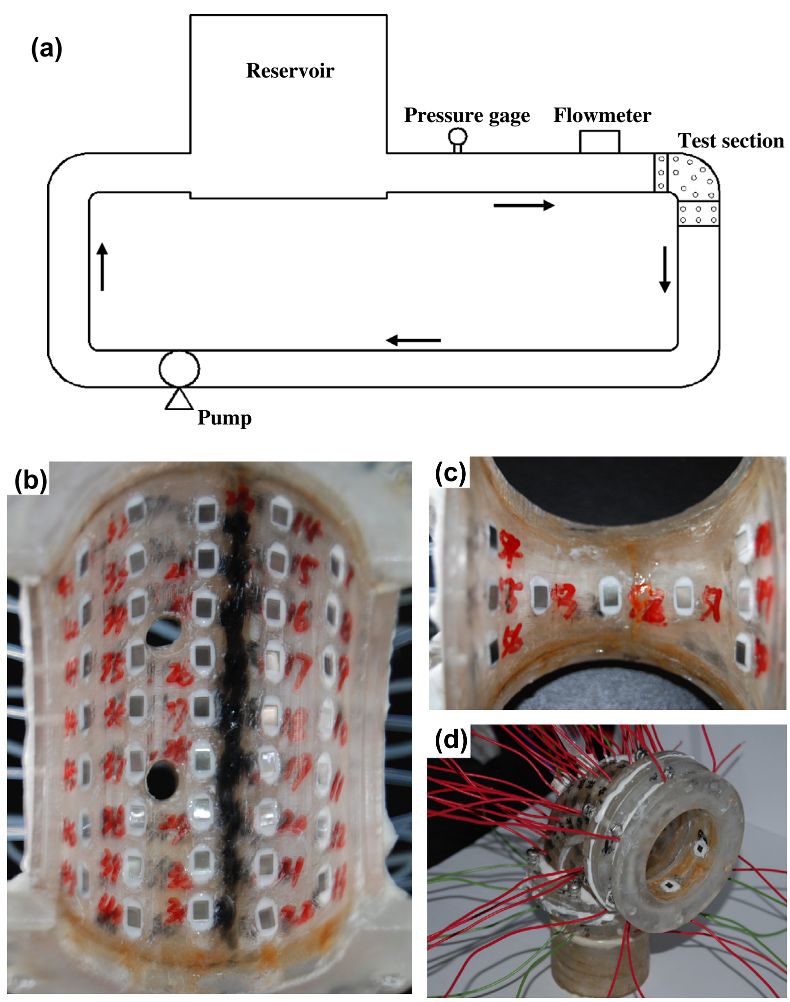

Fig. 1. Schematic diagram of flow accelerated corrosion loop test system and array electrodes: (a) loop test system, (b) distribution of array electrodes at the outer wall of elbow, (c) distribution of electrodes at the inner wall of elbow, and (d) the assembly of elbow test section.