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Inhibition effect of thioureidoimidazoline inhibitor for the flow accelerated corrosion of an elbow

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ABSTRACT

Inhibition effect of thioureidoimidazoline inhibitor (TAI) for the flow accelerated corrosion (FAC) at different locations of X65 carbon steel elbow was studied by array electrode and computational fluid dynamics (CFD) simulation. It is demonstrated that TAI is an anodic type inhibitor by remarkably inhibiting the anodic process. The inhibition efficiency at the inner wall is lower than that at the outer wall, which is associated with higher flow velocity, shear stress and turbulent kinetic energy at the inner wall of the elbow. The distribution of inhibition efficiency is in good accordance with the distribution of hydrodynamic parameters.

1. Introduction

Flow accelerated corrosion (FAC), which usually results in the failure of pipelines, is an important and inevitable challenge in the oil and gas industry [1,2]. Since FAC usually occurs under aggressive flow regime, the fluid hydrodynamics plays a significant role in FAC [3,4]. Hydrodynamics accelerates the mass transfer process and damages the protective corrosion products on the steel surface, and then promotes the corrosion of pipelines considerably [5–8].

In the oil and gas industry, the use of carbon steel associated with chemical inhibitors treatment remains the most common method for corrosion control due to its high strength, good weldability, and low cost [9–11]. Among the used inhibitors, imidazoline and its derivatives have been widely used in combating carbon dioxide corrosion because of their advantages such as high inhibition efficiency, low toxicity and easy production [12–15]. These nitrogen-based organic compounds can adsorb on the metal surface and create a barrier to the aggressive ions, thereby inhibiting the corrosion of carbon steel [16].

Presently, most research on carbon dioxide corrosion inhibitors is generally carried out under static condition, or using rotating cylinder electrode (RCE) or impingement jet system [17–19]. However, both RCE and impingement jet system cannot completely reflect the flow regime in a pipeline. The inhibition effect of inhibitors in these systems may not reveal the practical inhibition effect in industrial scale systems. In the situations where equipment and components are subject to turbulent flow, inhibitors may not function properly due to their inabilities to remain on the metals surface. The inhibition efficiency of inhibitors depends on the hydrodynamic parameters such as flow velocity and flow regime [20,21]. Therefore, the effect of hydrodynamics on inhibitor performance must be understood for the use of inhibitors for FAC. The application of a loop system can represent the real flow regime in pipelines [22]. Therefore, to simulate the flow regime in a pipeline more realistically, a loop system should be applied.

In the oil and gas transportation, elbow is an important part of most practical pipe configurations. However, the flow regime in a 90° elbow is subject to great changes in flow direction and flow velocity [23], thus leading to significant difference in the corrosion behavior at different locations of the elbow. In our previous work [24], it is demonstrated that the corrosion rates at the inner wall of the elbow are higher than those at the outer wall of the elbow. The maximum corrosion rate appears at innermost side while the minimum corrosion rate at outermost side of the elbow. The distribution of the measured corrosion rate is in good accordance with the distribution of flow velocity and shear stress at the elbow.

Due to the change in flow regime at the elbow, it is expected that there would be significant difference in the inhibition effect of inhibitors at different locations of the elbow. Array electrode technique, a configuration of multi-electrodes system, can be used

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for determining the inhibition effect difference at different locations of the elbow.

In this work, the inhibition effect difference of thioureidoimidazoline inhibitor (TAI) for the FAC at different locations of X65 carbon steel elbow was studied by electrochemical measurements and surface characterization with placing array electrode at different locations of the elbow. Computational fluid dynamics (CFD) simulation was also performed to reveal the flow regime at the elbow, and to determine the correlation between the inhibition efficiency of TAI and the hydrodynamics at different locations of the elbow.

2. Experimental and CFD simulation

2.1. Preparation of array electrode and solution

To study the inhibition effect of TAI for the FAC at an elbow, X65 pipeline carbon steel array electrodes with each exposed area of 5 mm × 6 mm were used in this experiment. The chemical composition (wt%) of X65 steel is composed of C 0.04%, Si 0.2%, Mn 1.5%, P 0.011%, S 0.003%, Mo 0.02% and Fe balance. An iron wire was welded to the back of each electrode to ensure electrical connection for electrochemical measurements. Before FAC test, each electrode surface was abraded with 800 grit silicon carbide paper, rinsed with deionized water, degreased with acetone and air-dried.

The testing solution, containing 90.44 g/L NaCl, 2.20 g/L KCl, 0.43 g/L $CaCl_2$, 0.43 g/L Na_2SO_4, 6.33 g/L $MgCl_2{\cdot}6H_2O$, 0.49 g/L $NaHCO_3$, was prepared from analytical reagents and deionized water to simulate the formation water of an oil field. Prior to FAC test, the solution was deaerated by purging CO_2 gas (purity was 99.95%) for 12 h. The pH value of the CO_2-saturated solution was 5.34. After deaeration, inhibitor was injected to the solution. An imidazoline derivative inhibitor, TAI, was used as the corrosion inhibitor in this study. The chemical structure of TAI was presented in Fig. 1. The molecule of TAI is composed of a five member imidazoline ring containing nitrogen element, a C-17 unsaturated hydrophobic group and a hydrophilic thioureido group attached to N1.

2.2. Loop system for FAC test

A vertical circulating loop system was used for FAC test, as shown in Fig. 2(a). It consisted of pipes, a centrifugal pump, a reservoir, a pressure gauge, a flow meter and array electrode test section. The solution was supplied from a 30-L reservoir and circulated through the centrifugal pump. The flow velocity was controlled by adjusting the rotational speed of pump using a speed controller. The flow velocity was measured by using a flow meter. A flow velocity of 4.0 m/s was selected according to the operating conditions in an oil field. The pipes were made of plexiglass tube with an inner diameter of 50 mm. A temperature control system was installed in the reservoir to control the temperature of solution. After pretreatment, array electrodes were mounted into the elbow test section with the same spacing distance in flow direction, and then sealed with silicone. Fig. 2(b) shows the assembly

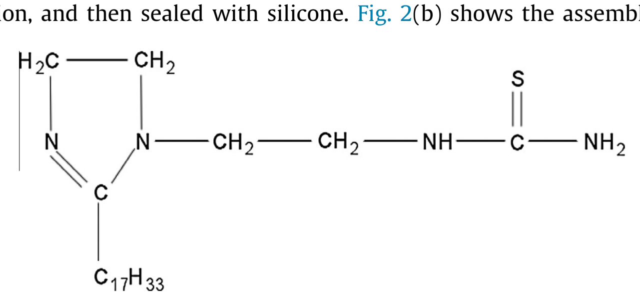

Fig. 1. Chemical structure of thioureidoimidazoline inhibitor.

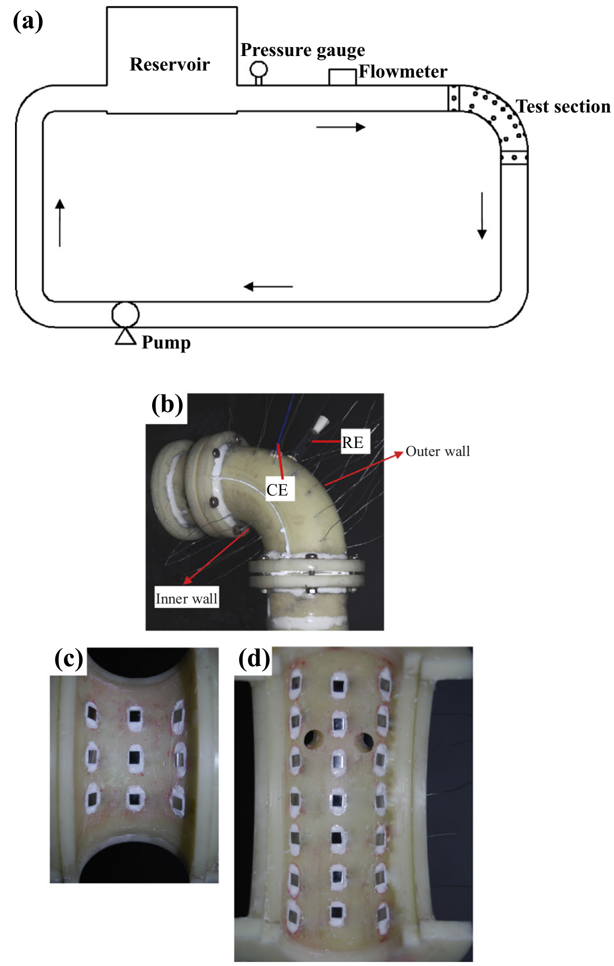

Fig. 2. Schematic diagram of the loop system and array electrodes for FAC test: (a) loop system, (b) assembly of the elbow test section, (c) array electrodes at the inner wall, and (d) array electrodes at the outer wall.

of the elbow test section, with 21 electrodes at the outer wall of the elbow, 9 electrodes at the inner wall of the elbow. The exposed surface of each electrode was in accordance with the internal surface of the elbow, as shown in Fig. 2(c) and (d).

2.3. Electrochemical measurements

FAC tests were performed in the loop system with a flow velocity of 4 m/s, inhibitor concentrations of 0 mg/L, 1 mg/L, 10 mg/L, 50 mg/L, 100 mg/L and 200 mg/L, test temperature of 60 °C and atmospheric pressure. As the TAI used in this study was an oil-soluble inhibitor, before being injected into the solution, TAI was dissolved into ethanol with a volume ratio of 1:4 (TAI to ethanol). The FAC tests lasted 5 h.

During the FAC tests, an electrochemical test system was used for in-situ electrochemical measurements at the fourth hour of the FAC tests. A three-electrode electrochemical cell was constructed in test section with the array electrode as working electrode (WE), a platinum plate as counter electrode (CE) and a saturated calomel electrode (SCE) as reference electrode (RE). To reduce the influence of the distances between the working electrodes and counter electrode on electrochemical measurements, the reference and counter electrodes were installed at the center of elbow, as shown in Fig. 2. Since the solution used in this study has a high conductivity, the influence of distance difference between each working electrode and reference and counter electrodes on electrochemical measurements can be neglected. To