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Erosion–corrosion behavior of 2205 duplex stainless steel in wet gas environments

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ABSTRACT

An unsteady state thin electrolyte film in the acidic environment of a natural gas pipeline was simulated using a self-assembled impingement jet system to study the corrosion behavior of 2205 duplex stainless steel (DSS) in gaseous environments with different relative humidity values. The electrochemical properties and surface morphologies of 2205 DSS samples were analyzed. Corrosion did not occur on the surface of 2205 DSS under wet conditions without gas impingement, whereas it did occur under the same conditions in the presence of gas flushing. The effect of gas-flow velocity was investigated with the help of computational fluid dynamics simulation. The results showed that the corrosion rate increased with accelerating flushing velocity in an environment with 80% relative humidity, particularly when the flow velocity was higher than 14 m/s. In addition, the sizes and number of pits increased remarkably at flow velocities higher than 14 m/s.

1. Introduction

In recent years, natural gas has played an indispensable role as a clean energy resource, which has resulted in an increasing demand for natural gas with every passing year. This increasing demand for natural gas underscores the need for the development of pipeline networks, which represent the most economical and reasonable means to transport natural gas (Li et al., 2015; Parsi et al., 2014). However, the existence of high concentrations of corrosive agents such as CO_2, H_2S, and Cl^- in acidic gas exploration fields, along with the high pressure of the gas being transported and high gas flushing velocity, place natural gas pipelines at risk for corrosion (Hu and Neville, 2009; Kahyarian et al., 2016; Bagheri et al., 2016; Zhao et al., 2016). To date, most studies on the corrosion of natural gas pipelines have focused primarily on corrosion in wet conditions (Lu et al., 2011; Najmi et al., 2015; Machado et al., 2012; Jevremovic et al., 2012), because natural gas does not normally go through deep dehydration and is directly transferred into the pipeline. Thus, when the temperature of the pipeline wall is lower than the dew point of water vapor inside the pipeline, which is mainly affected by the thermal conductivity, the water vapor will condense on the wall of the pipeline and dissolve CO_2, H_2S, and other acidic gases, resulting in corrosion (Wei, 2008).

To retard corrosion, the extracted gas is often subjected to a pre-dehydration process; however, severe corrosion failure still occurs during pipeline operation when humidity of the dehydrated gas is below the saturation humidity because the dehydration technology, which is limited by the actual drying conditions, cannot fully remove water from the gas Residual water molecules are affected by capillary action, physical condensation, and chemical adsorption; and invisible, thin electrolyte films containing dissolved H_2S and CO_2 form in the pipeline walls (Comizzoli et al., 1993). The actual delivery pressure of natural gas in pipelines is typically 4–8 MPa. Under such high pressures, the pipeline interior will suffer from significant gas flushing. This combination of electrochemical and mechanical factors namely, the corrosive environment and gas flushing, results in severe corrosion called flow-accelerated corrosion (FAC) that accelerates the damage to pipeline material. FAC can greatly shorten the service lives of some materials that are completely resistant to ordinary corrosion (Islam and Farhat, 2013). Thus, the study of FAC in natural gas environments has significant implications for industrial production.

In general, three methods are available for the study of FAC: the rotating cylinder electrode (RCE) or rotating disk electrode (RDE)

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technique, the loop system, and the impingement jet system (Papavinasam et al., 2003). The RCE or RDE technique (Harvey et al., 2007; Rajahram et al., 2009; Tobón et al., 2014; Jiang et al., 2005), which is simple and easy to implement, can investigate the corrosive process of the fluid passing though the sample surface; and the loop system can realistically simulate the fluid flow pattern in the pipeline (Malka et al., 2007; Rihan and Nešić, 2006; Zhang et al., 2013). However, both the RCE or RDE technique and the loop system are only efficient under liquid-dominated conditions. They are unable to accurately simulate corrosion behavior in wet or even half-dry conditions with gas flushing. An impingement technique should be used to investigate the corrosion process of samples subjected to gas flushing in wet environments (Galván-Luis et al., 2015; Hosseinloo et al., 2013; López et al., 2011; Sasaki and Burstein, 2007). With impingement, the flowing gas can be jetted from a nozzle to the electrode surface, and the velocity of the flowing gas along with the impact angles can be easily adjusted.

With the exploitation of oil and gas becoming more challenging, the originally used materials no longer meet the existing corrosion requirements. Because of its good mechanical properties, process performance, good ductility, and weldability, 2205 duplex stainless steel (DSS) has a wide range of applications in the construction of natural gas pipelines. However, few studies have investigated the erosion-corrosion of 2205 DSS in the acidic conditions encountered during the extraction and transport of natural gas Thus, investigating moisture-dependent erosion-corrosion of 2205 DSS, or corrosion kinetics under unsteady state thin electrolyte films, is vital for corrosion prediction.

In the present study, a self-assembled impingement jet system simulating an unsteady state thin electrolyte film in the acidic environment of a natural gas pipeline was employed to study the erosion-corrosion behavior of 2205 (DSS) at different relative humidity (RH) values. The RH of the gas was controlled by regulating the ratio of wet gas to dry gas In addition, computational fluid dynamics was employed to confirm the actual flushing velocity at the sample surface. The effects of gas flushing velocity and RH were investigated by evaluating the surface morphologies and electrochemical properties of the 2205 DSS samples.

2. Experimental

2.1. Material and sample preparation

The samples were prepared from 2205 DSS; the composition of 2205 DSS is presented in Table 1.

Samples with dimensions of 10 × 10 mm were cut from a sheet of 2205 DSS. The sample surface was first ground sequentially to 2000# grit SiC paper and then polished with 0.5 μm alumina polishing powder. After polishing, the metal surface was carefully washed with distilled water and acetone, and then dried prior to testing. NaCl particles were deposited on the sample surface using a TW-1000 sprayer aerogel before all the experiments to simulate the actual conditions of Cl^- deposition on the wall of a natural gas pipeline. The surface concentration of NaCl was approximately 2000 mg/m^2. Fig. 1 shows the surface morphology of a deposited sample; the NaCl particles were evenly distributed on the sample surface.

Table 1
Chemical composition of 2205 duplex stainless steel (wt%).

Steel	C	P	S	Cr	Ni	N	Mo	Mn	Si	Fe
2205	0.014	0.023	0.001	22.39	5.68	0.17	3.13	1.38	0.39	bal

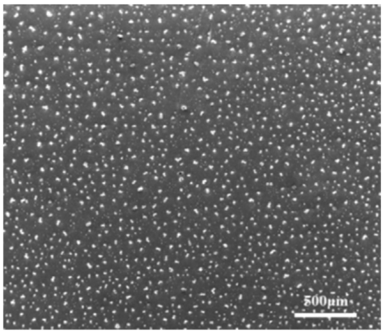

Fig. 1. Surface morphology of sample after NaCl deposition.

2.2. Experimental setup

Erosion-corrosion tests were conducted using the equipment shown in Fig. 2 at room temperature. The device used to control the humidity is depicted in Fig. 2(a). The gas used in the experiment was composed of CO_2 and N_2 at a ratio of 1:4 to simulate acidic natural gas The input gas was divided by the device into two parts: wet gas and dry gas Then, the relative humidity (RH) of the gas could then be controlled by regulating the ratio of wet gas and dry

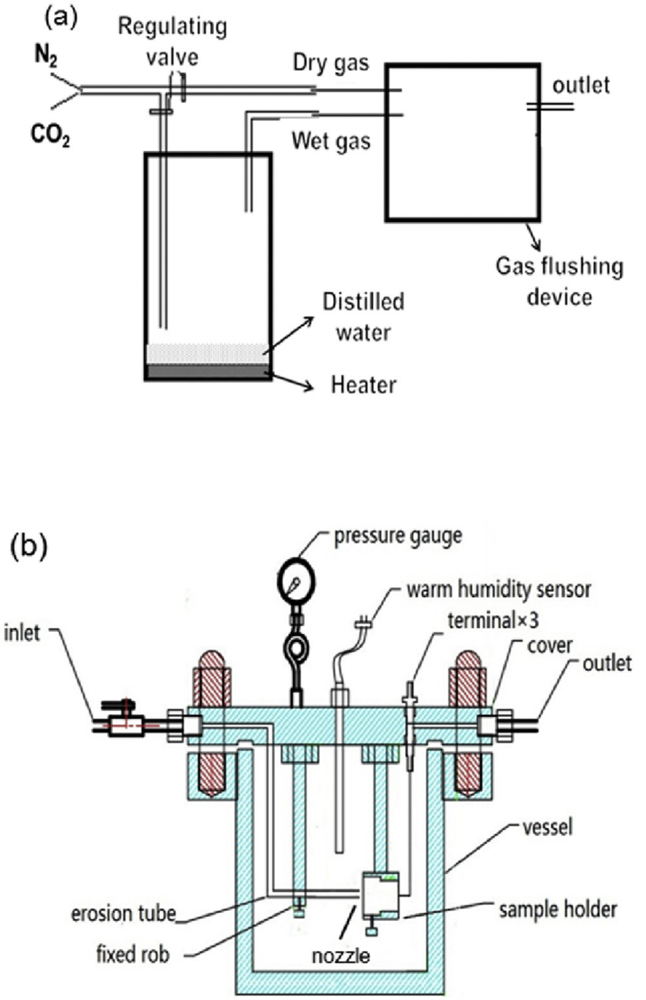

Fig. 2. Schematic diagram of the experimental set-up. (a) Humidity controlling device; (b) Gas flushing device.