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Failure analysis of a wet gas pipeline due to localised CO_2 corrosion

Mehdi Javidi*, Shima Bekhrad

Department of Materials Science and Engineering, School of Engineering, Shiraz University, Shiraz, Iran

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ABSTRACT

CO_2 corrosion is one of the main causes of failures of pipelines transporting wet gas. It can happen in general and localised form. In this study, the impact of the presence of iron carbonate scale which formed during process on CO_2 corrosion behaviour of API 5L X65 carbon steel has been investigated by electrochemical measurements. The chemical composition and morphology of the scale has been studied via X-ray diffraction and scanning electron microscope. The scales were found to be iron carbonate scale with trace amount of iron sulphide. The result of electrochemical analysis revealed that the uniform corrosion rate of carbon steel decreases in the presence of iron carbonate scale. Furthermore, the bare and continuously covered sample with iron carbonated did not show susceptibility to localised CO_2 corrosion. However, the presence of uneven iron carbonate scale or formation of thin, porous or defected scale can result in a potential difference between this area and adjacent area covered with compact scale followed by localised corrosion.

1. Introduction

Carbon steel is the preferred material choice for oil and gas transmission and distribution pipeline systems. API 5L is a material specification for the application of carbon steel in line pipes carrying gas, oil and water which provided in variety of heat treatment and mechanical strength. This class of material is susceptible to CO_2 corrosion in wet gas services. Pipeline failures are serious and expensive problems that might even end with catastrophic accidents [1–3].

The term “wet gas” means unprocessed natural gas containing liquid hydrocarbon (gas condensate) and water. When CO_2 which accompanying natural gas dissolves in formation water, carbonic acid is formed which is a weak, but corrosive acid to the carbon steel. The influencing parameters on CO_2 corrosion are CO_2 partial pressure, pH, temperature and flow rate and the presence of scales which have thoroughly been discussed in the literature elsewhere [4–6]. It is reported that in the absence of protective scales, corrosion rate increases with increasing CO_2 partial pressure and in high values of pH, increasing the CO_2 partial pressure enhances the protective scale precipitation which decreases corrosion rate [7]. Furthermore, increasing temperature accelerates the CO_2 corrosion rate in low pH, but in higher pH, as iron carbonate solubility decreases, formation of protective scales decreases the corrosion rate [6]. In the absence of inhibitor and non-scaling conditions ($pH < 6$, $T < 60\,^{\circ}C$), the increase in flow rate increases corrosion rate. On the other hand, in case of scaling condition ($pH \geq 6$, $T \geq 60\,^{\circ}C$) or presence of inhibitor film, the effect of flow rate is insignificant [4]. The mechanism of CO_2 corrosion for carbon steel is widely discussed and the iron carbonate ($FeCO_3$) has been proposed as the main corrosion product. Iron carbonate scale can be protective or non-protective depending on the water chemistry and temperature [4,6]. It is well-known that the media under the scale has different physical and chemical properties compared to the bulk electrolyte which can result in under deposit corrosion as a localised accelerated corrosion [8–10]. Thus, removing of scales is important for preventing corrosion. The use of scale inhibitors and mechanical removing via pigging are common removal methods of

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* Corresponding author.
E-mail address: mjavidi@shirazu.ac.ir (M. Javidi).

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hard scales and other deposits such as sand from the internal of the pipelines [11,12].

A number of environmental factors have been associated with the onset of localised corrosion of carbon steel including poor corrosion inhibition, local water separation in oil-water flow, differential condensation in wet gas flow, and flow disturbances such as weld beads, flanges, the presence of bacteria, solids, organic acids (such as acetic acid, formic acid and propionic acid) [13], hydrogen sulphide. On the other hand, temperature, pH of the solution, CO_2 partial pressure, salt concentration, flow rate and flow regime are the key environmental affecting parameters on the propagation of the localised CO_2 corrosion [14–16].

In this study, failure of an API 5L X65 carbon steel pipeline which failed because of internal localised CO_2 corrosion has been investigated. Also, the susceptibility of X65 carbon steel to localised CO_2 corrosion in the presence of iron carbonate scale has been studied.

2. Materials and methods

2.1. History of the pipeline

The investigated pipeline is a buried flow line which carrying wet gas from a gas condensate well to a gas manifold. The material of the pipe is API 5L X65 with outside diameter of 273 mm (10″ nominal pipe size, NPS) and 8.7 mm thickness which 4034 m long and with 3-layer polyethylene external coating. Also, the operating temperature of the pipeline is 55–60 °C and the pH was reported to be 4.8. Furthermore, the well-head pressure is 16.9 MPa with 72 ppm H_2S concentration in the gas phase. In other words, the partial pressure of H_2S is 3.3 kPa. The salt concentration in the water phase is reported to be around 50,000 ppm (30,000 ppm chloride ion).

2.2. Visual inspection

First of all, the location of the pipeline failure was inspected and the section of the pipe which failed due to corrosion was cut and delivered to laboratory for further studies. The internal corrosion of the pipe and also the presence on internal scale were investigated via scanning electron microscopy as mentioned in Section 2.5. Also, the primary data including the history of the pipeline construction and maintenance and also process condition were collected from the site.

2.3. Material characterisation

The chemical composition of the pipe was investigated by optical emission spectroscopy (OES, Foundry-Master Pro). Furthermore, in order to investigate the phase composition of the surface scale and view the cross sectional of the scale and performing electrochemical measurements some samples were cut from the body of the pipe. Three samples with 10 mm × 10 mm dimension were prepared, mounted in epoxy resin and wet ground up to 2000 grit SiC paper, then etched in Nital 2% and their microstructure was investigated via Leica optical microscope.

2.4. Phase composition and surface investigation of scale

Phase composition analysis of the hard scale was investigated via X-ray diffraction (XRD) technique using Bruker D8 Advance instrument operating at 40 kV and 30 mA with Cu-Kα radiation ($\lambda = 0.15405$ nm) with the scan rate of 3°/min. For this purpose, a sample with 10 mm × 10 mm dimension of the pipe with the presence of surface scale was used. The resulted XRD pattern was analysed by X'pert Highscore Plus Software Version 2.2.2 (PANalytical software). Furthermore, the surface morphology and cross section of the samples were investigated via scanning electron microscope (SEM, Cambridge Stereo-scan S360).

2.5. Electrochemical measurements

The surface area for both bare and scale covered samples was set to be 0.25 cm^2 with dimensions of 5 mm × 5 mm. A wire was soldered to the rear surface of the samples then; bare and scale covered samples were embedded in epoxy resin. The surface of some specimen was wet ground via 80, 180, 400 and 600 grit SiC papers then degreased by ethanol and rinsed with doubled distilled water and air dried for the study of the bare sample.

In order to investigate the effect of the presence of iron carbonate scale on CO_2 corrosion behaviour of X65 carbon steel, all the experiments were performed on both scale covered and bare samples. Electrochemical measurements were performed in a three-electrode-glass cell with API 5L X65 carbon steel as working electrode (WE) and platinum wire and saturated Ag/AgCl electrode as reference and counter electrodes, respectively. The working electrode was placed between the reference and counter electrode close to the reference electrode with fixed distance. The cell configuration is schematically shown in Fig. 1. The glass cell was filled with 400 ml of 3.5 wt% sodium chloride (NaCl; Merck) solution. Before each experiment N_2 gas was purged for 30 min to deoxygenate the solution. Then CO_2 gas was purged for 1 h in order to saturate the solution. It is necessary to note that purging of CO_2 was continued over the solution during the experimental measurements to maintain the saturation condition.

Electrochemical measurements were performed using potentiostat/galvanostat μAutolab-Type III. First of all, the open circuit potential (OCP) of the samples were monitored with time until the potential of the electrodes become stabilised. Then electrochemical impedance spectroscopy (EIS) was performed on the samples. The excitation amplitude of 10 mV over a frequency range of 100 kHz to 0.01 Hz at 10 points per decade was conducted using Frequency Response Analyser Software (FRA version 4.9.006). All