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Failure analysis of a carbon steel pipeline exposed to wet hydrogen sulfide environment

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ABSTRACT

Stress Corrosion Cracking (SCC) is one of the most common failure phenomena in the wet hydrogen sulfide environment. In this paper, the fracture failure of a fuel gas pipeline during operation has been analyzed. Through service environmental investigation, crack morphology detection, and stress analysis of fuel gas pipeline, the fracture has the morphology and characteristic of wet hydrogen sulfide SCC in the welding joint between pipeline and flange. The analysis shows that the abnormal martensitic microstructure in the pipeline has provided the advantage for SCC.

1. Introduction

Pipelines have been widely used to increase continuity of production, transport efficiency and reduce costs in process industry as well as in petrochemical industry [1–3]. But the petrochemical industry contains a variety of corrosive environment, and the most common and serious failure of pipe is stress corrosion crack caused by hydrogen sulfide [4,5]. Especially, a welding joint is susceptible to wet H_2S environment [6,7]. The main characteristics of SCC are the multi-source and the bifurcation of the intergranular or transgranular (or both) crack. In general, the crack orientation is perpendicular to the maximum principal stress.

The main factors that affect the SCC of the material are the external operating environment and the internal metallurgy and stress state of the components. The former is mainly affected by media, temperature, pressure and other factors, and the latter is mainly affected by the material elements, microstructure, heat treatment and other factors [8–11]. The wet hydrogen sulfide SCC has been paid more attention since 1950s. However, stress corrosion caused by wet hydrogen sulfide environment occurred from time to time.

The investigation of the pipe operating condition shows that the medium in the pipeline contains wet hydrogen sulfide, and the residual stress is high. In the present paper, the characteristics of SCC of wet hydrogen sulfide in pipeline weld are demonstrated by analyzing medium environment, testing chemical composition, detecting fracture and simulating residual stress in the welded joints. The results reveal that the synergistic effect of wet H_2S and high residual stress is the main factor that leads to the SCC.

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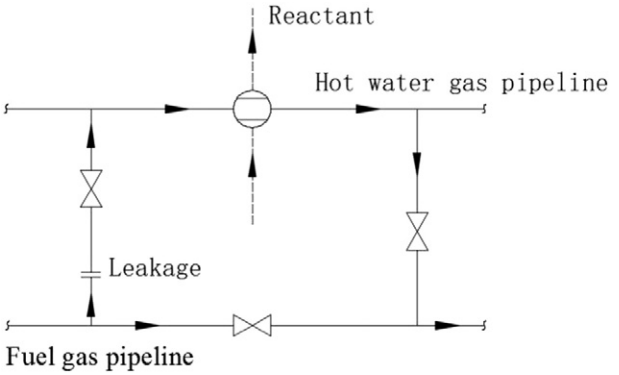

Fig. 1. Diagram of fuel gas pipeline.

Table 1
Composition of dry gas (volume percentage).

Element	H_2	C1	C2	C3	Propylene	C4	C5	H_2S
Content	42	28.4	20.6	4.8	0.7	2.9	0.5	0.1

2. Description

The leakage location of fuel gas pipeline in reforming unit is shown in Fig. 1. The leakage was caused by the cracking of the pipe at the cross line between the fuel gas pipeline and the hot water gas pipeline.

The fuel gas pipe was made of 20 steel, and the flange was made of 1Cr5Mo. The internal pressure of the pipeline is fluctuated between 0.5–0.77 MPa, and the operating temperature of the fuel gas is 18.64 °C. The main composition of dry gas in the pipeline is methane, which also contains a small amount of H_2S and condensed water. The specific composition is shown in Table 1.

3. Experimental analysis

3.1. Macroscopic fracture detection

The shear-lip is very narrow as shown in Fig. 2. When the crack is extended to the near surface, the shear stress is the leading factor and causes shear tearing. The outer surface of the fracture has obvious shear-lip, and the shear-lip is very thin. Shear-lip width reflects the material toughness, tear rate as well as the thickness of the component. Therefore, it can preliminary viewed that toughness of the weld joint is poor, which may be caused by missing or improper stress relief annealing.

(a) Fracture (b) Local amplification

Fig. 2. Macro appearance of fracture surface.