Testing Corrosion Rates on Steel Piping in Geothermal District Heating

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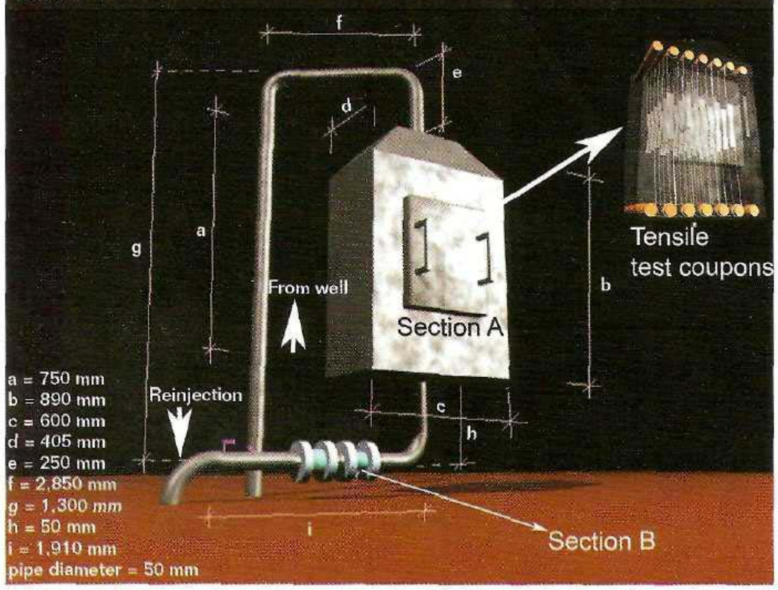
The St-37 carbon steel piping in a geothermal heating system experienced increasing corrosion leaks. Tests with pipe steel coupons showed that while uniform corrosion rates were low, pitting rates were high. Sulfate-reducing bacteria were the main cause. Changes in fluid velocities and the addition of a bacteriacide were recommended.

The Izmir-Balçova (Turkey) geothermal field is located 7 km west of the Izmir city center and covers an area of about 3.5 km^2. The nearby Balçova District Heating System has a maximum fluid capacity of 810 m^3/h and a designed heating capacity for 7,500 residences.[1] The geothermal fluid transmission lines from the wells to the surface and the distribution lines through the district heating network comprise St-37 carbon steel (CS) pipes (0.17% C, 0.3% Mn, 0.05% P, 0.05% S, and 0.3% Si), varying in diameters between 25 and 350 mm.[2] Because of the corrosive nature of the geothermal fluid, the city tap water is circulated in its own piping. The St-37 pipes are directly exposed to geothermal fluid in the fluid transmission lines. Although there had been only one transmission pipe failure during the first seven years of service, two failures occurred in 2005, after nine years of service. The main cause of the increased number of pipeline failures was the corrosion of the pipelines.

On-Site Corrosion Testing

An experimental set-up, directly connected to the end of the transmission line of geothermal well B-11, was used to assess the corrosion of St-37 steel tensile test coupons prepared in accordance with ASTM E8[3] in geothermal fluid (Figure 1). The geothermal fluid entered the set-up from the top of section A with a relatively low velocity, 0.02 m/s, and then was reinjected into the well after flowing through section B with a relatively high fluid velocity, 9.6 m/s. Before insertion into the experimental set-up, the surfaces of the tensile test specimens were polished to 6 μm. The specimens were hung between cylindrical rods in section A using a heat-resistant rope. The flat surfaces of the specimens remained parallel to the fluid flow (Figure 1). Only three specimens were inserted in section B. The average temperature of the fluid was 96°C and contained relatively high amounts of sodium (328 mg/L), chlorine (208 mg/L), and sulfate (161 mg/L) ions. As with normal well operations at the site, an Sb-based inhibitor (Ferrofos 8441 AF*) was added into the geothermal fluid as a cathodic inhibitor. The tensile test samples were taken from the experimental set-up after prescribed time intervals—between 124 and 1,620 h. Following the uniform and pitting corrosion rate measurements, the samples were tensile tested at a cross-head speed of 10 mm/min. The maximum pit depths of the corroded specimens were determined by surface roughness measurements.

FIGURE 1

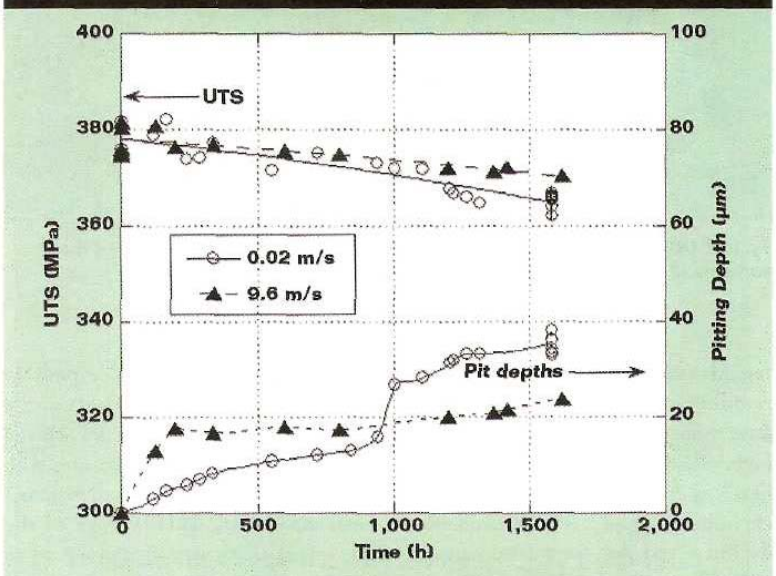


Schematic of the experimental set-up used and St-37 specimens in section A.

Uniform Corrosion

At both fluid velocities, the uniform corrosion rate (per ASTM G01-90[4]) reached a constant value, 0.0178 and 0.022 mm/y for 0.02 and 9.6 m/s, respectively, after ~500 to 600 h exposure time. The uniform corrosion rate was ~25% higher in high-velocity fluid tests. The measured corrosion rates showed good correlation with the reported corrosion rates (0.017 and 0.023 mm/y) for a CS exposed to a geothermal fluid of 70°C and 5.5 to 8.5 pH.[5] An amorphous porous scaling (fouling) was microscopically observed to cover the surfaces of the samples tested at various exposure times between 124 to 1,620 h.

FIGURE 2



Variation of maximum pit depth and ultimate tensile strength with exposure time.

Pitting Corrosion

Pit formation and growth processes are known to be statistical in nature; therefore, the maximum pit depth measurements were initially performed on 10 specimens exposed to the fluid for 1,581 h at 0.02 m/s to determine the variation of the maximum pitting depth in samples of the same exposure time. Results showed that the maximum depth measurements varied between 33 to 38 µm for the constant exposure time. The measured maximum pit depths for specimens exposed to the fluid at varying times therefore had a ±5 µm deviance. Figure 2 shows the variation of maximum pit depths and ultimate tensile strength (UTS) values of the tested specimens with exposure time. At longer exposure times, corresponding to the

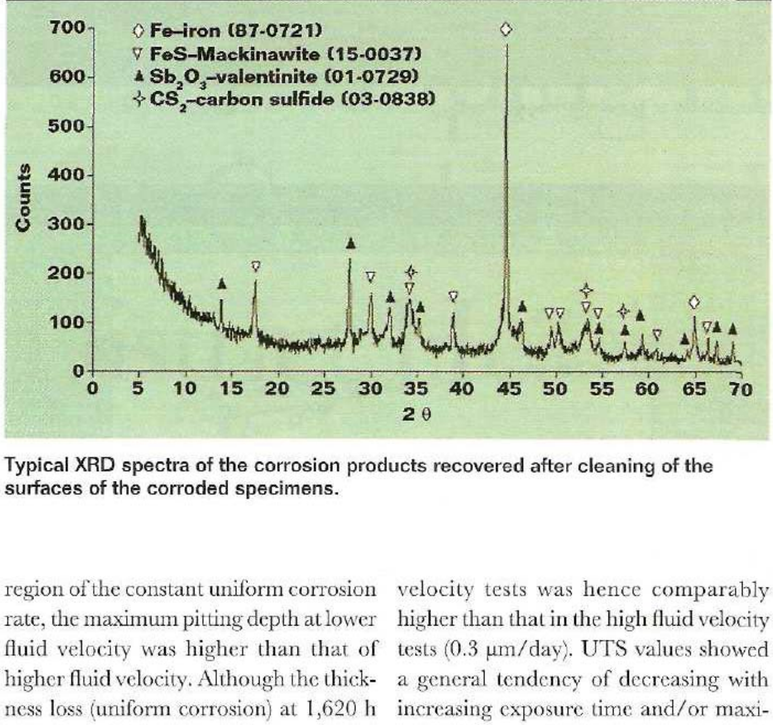
*Trade name.

FIGURE 3

(a) (b)

SEM image showing (a) SRBs and (b) accumulation of the SRB in a pit.

FIGURE 4



Typical XRD spectra of the corrosion products recovered after cleaning of the surfaces of the corroded specimens.

region of the constant uniform corrosion rate, the maximum pitting depth at lower fluid velocity was higher than that of higher fluid velocity. Although the thickness loss (uniform corrosion) at 1,620 h exposure time and at 9.6 m/s fluid velocity was ~3.71 µm, the measured maximum pit depth was 23.84 µm. At a similar exposure time, 1,581 h, the thickness loss in the specimens tested at 0.02 mm/s was smaller, 3.220 µm, showing the lower rate of uniform corrosion in low fluid velocity tests, while the pit depth was relatively higher, 35.78 µm. The average maximum pit depth corrosion rate (0.617 µm/day) in low fluid velocity tests was hence comparably higher than that in the high fluid velocity tests (0.3 µm/day). UTS values showed a general tendency of decreasing with increasing exposure time and/or maximum pit depth. UTS values of the specimens decreased from 374.58 to 381.64 MPa in untested specimens to 364.27 to 367.71 MPa in tested specimens at 1,581 h exposure time and 0.02 m/s fluid velocity. The reductions in the UTS values of the specimens tested at 9.6 m/s fluid velocity were moderate, from 374.58 to 381.64 MPa in uncorroded specimens to 370.17 to 374.79 MPa after 1,620 h exposure time (Figure 2).

Sulfate-Reducing Bacteria

The microscopic analyses of the corroded specimen surfaces before and after cleaning showed evidence of sulfate-reducing bacteria (SRB) activity, particularly in the pits (Figure 3). The x-ray diffraction (XRD) analysis on the corrosion products recovered after cleaning the surfaces of the specimens confirmed that the corrosion products were the same after 336, 845, and 1,207 h exposure time and were composed of elemental iron, mackinawite (FeS), valentinite (Sb_2O_3), and carbon sulfide (CS_2) (Figure 4). The SRBs make use of the H^+ to reduce sulfate to FeS through the following reactions:[6]

$$8e^- + 8H^+ \rightarrow 8H \quad (1)$$

$$SO_4^{-2} + 8H \rightarrow S^{-2} + 4H_2O \quad (2)$$

$$Fe^{+2} + S^{-2} \rightarrow FeS \quad (3)$$

Therefore, the formation of FeS was attributed to SRB.

The number of SRB, however, was microscopically observed to decrease in the samples tested at 9.6 m/s fluid velocity as compared with the samples tested at 0.02 m/s fluid velocity. Microbiologically influenced corrosion in a geothermal system was previously shown in several studies. SRB activity at temperatures >100°C was reported for a geothermal fluid.[7] Amalhay further reported an increased number of SRBs on the corrosion coupons as compared with the circulating geothermal fluid.[8]

Conclusions

This investigation was conducted to determine the corrosion behavior of St-37 pipeline steel in a geothermal district heating system at two different fluid velocities. It was found that although the uniform corrosion rates were relatively low, the pitting corrosion rate, mainly driven by the SRB activity, was relatively high and more pronounced at low fluid velocities. The decrease in the UTS of St-37 showed good agreement with the measured maximum pitting depths found in the tested samples. Since St-37 steel material is known to be prone to the pitting type corrosion, a biocide chemical addition was recommended to reduce SRB activity. Further, the fluid velocity of 2 to 3 m/s in the transmission line in a normal operation may also be increased to higher values to reduce the pitting corrosion rate.

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