FAILURE ANALYSIS OF A DIFFERENTIAL PIPE

EXAMPLE REPORT

Modified from Original Report

Casey Julich-Trojan, B.Eng.
Metallurgist

Shane Turcott, P.Eng., M.A.Sc.
Principal Metallurgist
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SUMMARY

The differential carbon steel pipe failed due to high temperature hydrogen attack (HTHA). Whereas the line was supposed to have been closed since the repurposing of the unit in 2008, product flow through the line had resulted in hydrogen exposure at temperatures leading to HTHA damage. HTHA damage had severely weakened the steel, allowing it to break when a carpenter accidently hit the line during scaffolding erection.

Other lengths of the differential lines that had experienced recent product flow would also have suffered HTHA damage. It is recommended these damaged lengths be closed off or removed from service immediately.

1.0 INTRODUCTION

No Peaking submitted samples of a cracked pipe from Reactor Top Differential. Figure 1 displays a provided photograph of the cracked pipe. Cracking at the pipe/flange fillet weld had occurred when a carpenter had accidently hit the pipe during scaffolding erection.

The pipe comprised of ¾” Schedule 80 ASTM A106 Grade B steel and the flange was made from ASTM A105N steel. The pipe had been installed in 1996 with the original construction of the unit. In 2008, the unit had been repurposed and the differential lines had been closed. Since 2008, the hydrogen service reactor contained hydro cracker bottoms, operating at 640°F (340°C) and 900 psig.

Steel Image was requested to determine the nature of failure.

2.0 EXAMINATION

Figure 2 displays the samples submitted for analysis. The samples included (1) the flange side of the fracture and (2) two feet of piping beyond the fracture. Brittle fracture had occurred within the pipe material at the pipe-flange weld toe.

Transverse cross-sections of the pipe taken (a) adjacent the fracture and (b) remote the fracture (~2ft remote) found the pipe to have sustained extensive high temperature hydrogen attack (HTHA, Figures 3 and 4). Damage along the internal surface had occurred in the form of decarburization and intergranular micro-fissures classic for HTHA. At both sites evaluated, the microstructural damage could be seen extending through approximately half the pipe wall thickness.

The HTHA damage had extended beyond the length of pipe submitted for analysis. Therefore, HTHA damaged differential piping still remained in the field.
Note that the line was supposed to have been closed since repurposing the unit in 2008. The uniform HTHA damage along the length of the pipe suggested that flow may have still been occurring since that repurposing. Further investigation by [Redacted] confirmed that portions of the differential lines had still be experiencing product flow during recent service.

Examination of the fracture surfaces further confirmed that pipe fracture had occurred due to the HTHA damage. Scanning electron microscopy (SEM) found the fracture to exhibit predominantly intergranular features indicative of HTHA damage (Figure 5). As a point of interest, the intergranular fracture features extended to the outer diameter of the pipe’s fracture which was beyond microstructural damage observed by optical microscopy (Figure 7).

3.0 CONCLUSIONS

The differential pipe had failed due to high temperature hydrogen attack (HTHA). Whereas the differential line was supposed to have been closed during the repurposing of the unit in 2008, recent product flow through the line had resulted in hydrogen exposure at temperatures leading to HTHA damage. HTHA damage had severely weakened the steel, causing it to break when accidently impacted by a carpenter during scaffolding erection.

Although the occurrence of HTHA can be empirically predicted by the Nelson Curve, the mechanism of damage is not well understood. The most prevalent theory is that hydrogen ions are introduced into the steel from the hydrogen gas and/or corrosion. These hydrogen ions react with the carbon within the steel, forming methane gas-filled micro-fissures within the steel. The combination of (a) expected decarburization from the steel, (b) micro-fissures and (c) internal pressure within the micro-fissures are expected to degrade the steel’s properties/integrity.

Other lengths of the differential lines that had experienced flow since repurposing would also have suffered HTHA damage. These pipe lengths would be at high risk of failure. It is recommended these damaged lengths be closed or, preferably, removed from service immediately.

The Reactor shell comprised of alloyed 1¼Cr, ½Mo steels that were weld clad with stainless steel. These alloys have greater resistance to HTHA damage. Therefore, damage of the carbon steel lines does not necessarily indicate damage to the alloyed steel components of the reactor. Still, it is recommended that a thorough review of the reactor and neighbouring components be conducted to ensure all remaining components have been operating within the safe limits prescribed by API RP 571 and the Nelson Curve.
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Figure 1: Photograph provided of the cracked pipe as-found.

Figure 2: Photograph displaying the samples submitted for analysis and the pipe fracture at the weld toe.
Figure 3: Micrographs of the transverse cross-section taken one inch from the fracture. The pipe had sustained extensive high temperature hydrogen attack (HTHA) damage. HTHA damage had occurred in the form of decarburization and micro-fissures extending through half the pipe wall thickness. Etched using 3% nital.
Figure 4: Micrographs displaying the remote cross-section of the pipe to have also sustained HTHA damage. The HTHA damage at this site was similar to that found at the fracture, indicating similar thermal history. Although this line should have been closed since repurposing in 2008, the uniform HTHA damage suggested that the line had experienced product flow. Etched using 3% nital.
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Figure 5: (a,b) Photographs displaying the fracture on the pipe side in the as-received condition and after cleaning. (c-f) SEM images displaying the fracture features to consist of smooth, intergranular features expected for HTHA failure. SE1, 20kV.
Figure 6: Photographs displaying the fractured flange and pipe having been cut in the longitudinal orientation, then mounted together. Micrographs illustrated in Figure 7.
Figure 7: Micrographs illustrating the HTHA damage at the fracture. The resulting decarburization, micro-fissures and internal gas pressure had severely weakened the joint, leaving it susceptible to fracture when accidentally hit by the carpenter. Etched using 3% nital.