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MATERIAL SELECTION FOR REPAIR OF DAMAGED PROCESS PIPING IN HIGH-TEMPERATURE SULFIDATION SERVICE IN THE NO. 4 CRUDE UNIT[1]

Executive Summary

On August 6, 2012, a fire occurred in the No. 4 Crude Unit ("Crude Unit") at the Richmond Refinery, owned and operated by Chevron U.S.A. Inc. ("CUSA"). While the investigation into the cause of the fire is ongoing, preliminary information indicates that the fire occurred in the area of a leak in a 5-feet-long section of the 200-feet-long 4 side-cut carbon steel pipe in high-temperature service. It is believed that the leak resulted from accelerated sulfidation corrosion in the 5-feet-long section of pipe, which had low-silicon content (less than 0.10 wt% Si).

CUSA has submitted applications to the City of Richmond for permits pursuant to the California Fire Code ("CFC") to replace fire-damaged piping in high-temperature sulfidation ("HTS") service in the Crude Unit with 9 Chrome alloy pipe ("9Cr"). Because questions have been raised by certain members of the public about CUSA's selection of 9Cr, the City has temporarily delayed issuing permits for such work and Bill Lindsay, Richmond City Manager, has requested additional information concerning CUSA's selection of material.

As explained below, CUSA's selection of 9Cr pipe to replace fire-damaged pipe in HTS service satisfies all engineering and fire-safety standards, and other industry recommended practices, for the use in the Crude Unit. While certain members of the public and the Chemical Safety Board ("CSB") have suggested 300-series stainless steel ("300 SS") as an alternative material based on its increased resistance to sulifdation corrosion, the use of 300 SS would introduce a new damage mechanism not present with 9Cr that is more difficult to monitor and inspect than sulfidation corrosion.

Materials Selection Process

As the owner and operator of the Refinery, CUSA has the responsibility and technical expertise necessary for selecting materials for a particular service based on sound engineering and industry practices. In selecting materials, CUSA relies upon experienced materials engineers, who use their expert judgment to choose robust and predictable materials suitable for the planned service, taking into account the risks presented. Any material selection must be supported by a comprehensive monitoring and inspection program to ensure that the selected material is performing consistent with expectations.

[1] Prepared with the assistance of Barbara Smith, Senior Business Manager, Richmond Refinery, CUSA.

The material selection process is complex and based upon consideration of multiple factors, including operating conditions (particularly temperature), operating history, process chemistry, velocities and other flow conditions, local unit conditions, potential unusual operating conditions, and turnaround considerations. It is also important to consider the risk from all possible damage mechanisms, as well as the ability to monitor the equipment against those damage mechanisms. Otherwise, a decision could inadvertently shift the risk from one damage mechanism to another. Whenever possible, CUSA selects a material that best addresses these multiple considerations.

The City's Scope of Review

Once materials are selected for the repair work, CUSA applies for permits from the City, which reviews the permits for compliance with the California Building Standards Code, inclusive of the California Building Code ("CBC") and the CFC, as implemented by the City.[2] The installation of "process piping" such as the piping being replaced as part of the Crude Unit repair is regulated in two ways:

- Support structures for the piping systems require a building permit pursuant to the CBC;
- The materials for process piping and the design of the piping system are reviewed for compliance with the CFC.

Pursuant to the CFC, the City's permitting role is to confirm that the materials CUSA has selected to replace fire-damaged piping in HTS service in the Crude Unit comply with the engineering standards of the American Society of Mechanical Engineers ("ASME") Code for Process Piping ("ASME B.31.3") and the fire-safety standards of the National Fire Protection Association ("NFPA") Flammable and Combustible Liquids Code ("NFPA 30").[3]

Technical Analysis for Replacement of Fire-Damaged Pipe in HTS Service in the Crude Unit

Pursuant to ASME B31.3 and NFPA 30, carbon steel, 5 Chrome alloy ("5Cr"), 9Cr, and 300 SS are suitable for service in the Crude Unit. In addition to adhering to these engineering and fire-safety standards, it is important to consider a material's sulfidation resistance when selecting materials for HTS service. API 939-C identifies carbon steel with adequate silicon, 5Cr, 9Cr, and 300 SS as examples of materials suitable for HTS service, depending on various factors.[4] An additional consideration in selecting materials for HTS service is prior experience and information concerning a material's past performance in that service.[5]

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[2] See Richmond Municipal Code ("RMC") § 6.02 et seq.
[3] A further description of the manner in which engineering and fire-safety standards are promulgated and incorporated into the City's review is provided in Appendix I.
[4] See Appendix II.
[5] Id.

Taking into account the above-described factors, as well as the risks presented, the Refinery Materials Engineer exercised her expert judgment and selected 9Cr as the appropriate material for replacement of fire-damaged piping systems in HTS service in the Crude Unit. This decision was later confirmed by other experts who have since reviewed the decision.

As noted, 9Cr satisfies all regulatory engineering and fire-safety standards for containment and processing of crude oil. Further, as shown by the Modified McConomy Curves in the API 939-C ,the sulfidation corrosion rates of carbon steel with adequate silicon, 5Cr, 9Cr, and 300 SS demonstrate that each may be suitable for HTS service in the Crude Unit, in particular when one takes into account the Crude Unit's operational history.[6] Thus, based on all applicable technical standards and recommended practices, 9Cr is a suitable material for replacing the fire-damaged piping systems in HTS service in the Crude Unit, and provides significantly increased resistance to sulfidation corrosion when compared to the low-silicon carbon steel component involved in the August 6 incident.

CUSA understands that certain members of the public and the CSB have commented that 300 SS might be a better material for the repair work based on its higher sulfidation resistance as compared to 9Cr, in particular in light of the February 2012 loss of containment that occurred at the BP Cherry Point Refinery, where the pipe that failed was 9Cr and the damage mechanism was sulfidation corrosion.

While the BP Cherry Point incident may seem relevant to the selection of 9Cr for parts of the repair work, based on the publicly disclosed BP investigation of this incident, we do not believe the incident presents an analogous situation to the Richmond Crude Unit. The piping in that instance appears to have been a semi-stagnant "dead-leg" which, after 29 years in high-temperature service, allowed corrosives to build-up in a vapor space at the top of the piping, leading to the failure. We understand that the flowing lines in HTS service in the BP Cherry Point refinery had no problems, and that BP replaced the pipe in question with 9Cr. Thus, this incident does not support a conclusion that 9Cr is not suitable for HTS service, but rather supports industry efforts to eliminate "dead-leg" systems as much as possible and emphasizes the importance of existing industry standards requiring a specific "dead-leg" inspection program for "dead-legs" remaining in service.

Importantly, the selection of 300 SS would also introduce a new damage mechanism to the Crude Unit in the form of stress corrosion cracking ("SCC") from chlorides, and potentially from "polythionic" acids, that would not occur with 9Cr.

Whereas 9Cr is immune to SCC, chlorides in the presence of water may cause SCC of any 300 SS piping at temperatures above about 140ºF. Losses of containment due to chloride SCC are well-documented in the literature.[7] Further, CUSA has identified 10 instances of SCC in stainless steel pipes in high-

[6] Id.

[7] ASM Metals Handbook, Volume 13C "Corrosion: Environments and Industries;" "Corrosion in Petroleum Refining and Petrochemical Operations," R.D. Kane editor

temperature service in crude units, mostly from chlorides.[8] The pipes that cracked in these instances were in similar or analogous service to the piping being replaced as part of the repair of the Crude Unit, which is subject to potential risks from chloride SCC because the crude oils processed contain chlorides, as does ambient moisture such as that from the drift from the adjacent No. 3 CAT Cooling Tower.

Another potential damage mechanism with 300 SS is "polythionic" SCC, which occurs when sulfur scales combine with oxygen and water to form sulfurous acids that can crack "sensitized" stainless steel. Although the potential for this damage mechanism can be mitigated by using the appropriate grade of stainless steel, it is still a relevant consideration.[9]

A final but vitally important consideration in selecting materials for a particular service is the ability to monitor the equipment against damage mechanisms. A key reason for the selection of 9Cr is its predictable corrosion rate, which makes monitoring of sulfidation corrosion more effective. On the other hand, SCC from chlorides or polythionic acids results in microscopic cracks that are difficult to detect prior to failure. Thus, the use of 9Cr presents less overall risk that 300 SS when it comes to detecting and predicting corrosion, and does not introduce a new damage mechanism to the Crude Unit.

CUSA's selection of 9Cr adheres to the applicable engineering and fire-safety codes and is the best choice for purposes of fire and operational safety because it effectively reduces the risk from, and provides the ability to effectively monitor, sulfidation corrosion, while avoiding the risk of SCC altogether.

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[8] See Appendix III.

[9] The benefits of stainless steel do sometimes outweigh the potential for SCC, such as when a refinery processes "naphthenic acid" crudes. The Richmond Refinery does not process such naphthenic crudes, however, so this is not a consideration for the selection of materials for repair of the Crude Unit.