N. American Site #9 - Naphtha Hydrotreater (NHT) Feed/Effluent Exchanger Shell Rupture

Safety Impact			Environmental Impact		Production Impact		Damage
Fatalities	Injuries	First Aid	Leak Volume	Reportable	Days	Cost	Cost
7	0	0	Large	Yes	?	$$$$$	$$$$

The Incident

The shell of a Feed/Effluent Exchanger on a Naphtha Hydrotreater (NHT) failed catastrophically resulting in an explosion and intense fire which burned for more than 3 hours. The incident fatally injured 7 people (6 operators and 1 shift supervisor) who were working in the immediate vicinity of the ruptured exchanger at the time of the incident.

Background

The NHT Feed/Effluent Exchanger train was configured with 2 identical parallel sets of 3 shells in series with reactor feed on the tubeside and reactor effluent on the shellside. At the time of the incident 1 of the 2 exchanger trains was being placed back in service following off-line cleaning and inspection. This “non-routine” restreaming procedure includes gradual and concurrent manipulation of several large isolation valves, requiring the assistance of several additional Operations personnel.

It is common practice for NHT Feed/Effluent Exchanger trains to have graded design temperatures which determine metallurgy selection for each shell. In this case, the hot shells were fabricated from C-0.5 Mo steel (SA 302-B) factory clad with a 0.125 mm (1/8") thick 304 SS liner, the middle shells were fabricated from carbon steel (SA 515-70) partially factory clad with a 0.125 mm (1/8") thick 316 SS liner and the cold shells were fabricated from unlined carbon steel (SA 515-70). The circumferential and longitudinal seam welds used in fabrication of the shells were not post-weld heat treated (“stress-relieved”). The shells had been in service since the first startup nearly 40 years earlier.

Causes

The immediate cause of the explosion and fire was loss of primary containment (LOPC) due to high temperature hydrogen attack (HTHA) of the carbon steel shell of one of the middle exchangers at a point just downstream of the 316 SS partial lining. Critical factors were the high residual stress levels present in areas around the seam welds of the shell due to lack of post-weld heat treatment and presence of additional personnel to assist in restreaming the second train of exchangers after off-line cleaning. Root causes included inaccurate Nelson curve for carbon steel (this curve predicts susceptibility to HTHA as a function of process temperature and hydrogen partial pressure based on observed industry experience), ineffective hazard identification and failure to apply inherently safer design principles.

Lessons

HTHA occurs when carbon and low alloy steels are exposed to high hydrogen partial pressures at high operating temperatures (service exposure time is cumulative). The hydrogen reacts with carbides in the steel to form methane (CH_4) which cannot diffuse through the steel. The loss of carbide weakens the steel and the accumulation of CH_4 pressure in the steel creates cavities and fissures which eventually combine to form cracks. HTHA damage is most likely to occur in highly stressed areas and heat-affected zones (HAZs) around welds.

It is critically important for new and existing units in hydrogen service that equipment is checked against the relevant Nelson Curve for startup, shutdown and transient conditions to identify appropriate mitigation strategies against HTHA. Mitigations may include 1) selection of inherently safer (more HTHA-resistant) materials such as Cr-Mo steels, 2) imposition of strict operating limits, 3) provision of appropriate instrumentation to enable proper monitoring and 4) rigorous enforcement of startup, shutdown and emergency procedures. Note that transient conditions might include gradual changes to operating conditions due to fouling of equipment or deactivation of catalysts.