Lessons Learned Database
Individual Incident Summary Report

IChemE Safety & Loss Prevention Special Interest Group

Incident Title	**Catastrophic Heat Exchanger Shell Rupture**	
Incident Type	Explosion and Fire	
Date	2nd April 2010	
Country	USA	
Location	Anacortes, WA	
Fatalities	**Injuries**	**Cost**
7	0	Unknown

Incident Description

A Naphtha Hydrotreater (NHT) Feed/Effluent Exchanger train comprised 2 parallel banks of 3 stacked shells in series. One of the two banks was being placed back in service after off-line cleaning and inspection. The procedure for this "restreaming" operation includes gradual and concurrent operation of several large isolation valves, requiring the help of several Operations personnel. While the restreaming operation was taking place, the carbon steel (CS) shell of the middle exchanger of the adjacent "in-service" bank of 3 exchangers ruptured catastrophically along the seam welds of the shell. The rupture caused a massive release of hot hydrogen and naphtha which auto-ignited and exploded. Seven employees working in the immediate vicinity of the exchangers were fatally injured.

Incident Analysis

Basic cause was a loss of primary containment due to rupture of the carbon steel shell caused by high temperature hydrogen attack (HTHA) at a point just downstream of the internal 316 SS partial lining.

Critical factors included: 1) 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), 2) The shell had been in service for a cumulative total of 38 years when it failed, 3) High residual stresses were present in the seam welds of the shell due to lack of post-weld heat treatment (PWHT), 4) The reactor feed side (tubeside) of the exchanger had a history of significant fouling (resulting in higher shell temperatures), 5) There was no instrumentation on either the inlet or outlet stream of the intermediate shells, 6) Additional Operations personnel were present to assist in restreaming (multiple large isolation valves).

Root causes included: 1) Inadequate process safety management system (required proof of danger rather than proof of effective risk mitigation), 2) Inadequate process monitoring (inadequate thermometry), 3) Inadequate process hazard analysis (design parameters used for assessing HTHA susceptibility rather than actual operating conditions), 4) Failure to apply inherently safer design principles (Cr-Mo alloy steels have greater resistance to HTHA), 5) Inadequate regulatory oversight (no requirement for adopting Safety Case methodology or applying inherently safer design principles).

Lessons Learned

1) The Nelson curve for carbon steel has been revised,
2) HTHA is most likely in heat affected zones (HAZs) around welds,
3) Gradual changes to operating conditions (eg. heat exchanger fouling or catalyst deactivation) may lead to an accidental breach of operating limits,
4) Abnormal (transient) operating conditions (eg. startup, fouling, shutdown, etc) can create major process safety hazards,
5) For CS and C-0.5 Mo steel in hydrogen service, the safe operating limit should be > 28 °C (50 °F) and > 3.5 bar (50 psi) below the new Nelson curve,
6) Refinery equipment and piping susceptible to HTHA should be replaced with inherently safer materials (eg. low Cr-Mo alloys) to mitigate the risk.

More Information

1) "Catastrophic Rupture of Heat Exchanger", US Chemical Safety and Hazard Investigation Board (CSB), Report No. 2010-08-I-WA (2014),
2) "Rupture of a Heat Exchanger at a Refinery Causes Fatalities", T. Fishwick, IChemE Loss Prevention Bulletin 228 (December 2012),
3) "API RP 941 Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants" (2016).

Industry Sector	Process Type	Incident Type
Oil & Gas	Naphtha Hydrotreating	Explosion & Fire
Equipment Category	**Equipment Class**	**Equipment Type**
Mechanical	Heat Exchanger	Shell & Tube