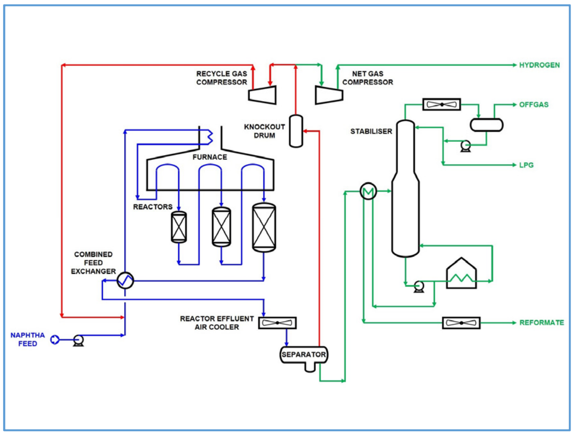
European Site #1 - Cat Reformer (CRU)
Combined Feed Exchanger Channel Head Failure



Safety Impact			Environmental Impact		Production Impact		Damage
Fatalities	Injuries	First Aid	Leak Volume	Reportable	Days	Cost	Cost
0	0	0	0	No	30	$$$	$$$

The Incident

The channel head of a combined feed exchanger on a semi-regenerative catalytic reforming unit (CRU) failed catastrophically whilst it was being subjected to hydrostatic testing (“hydrotesting”) during turnaround. The intended hydrotest pressure was 140 barg (2036 psig), but the rupture occurred at only 93 barg (1350 psig). Fortunately, no one was injured, but the turnaround duration was extended by 20 days while the plant was modified to allow startup of the unit with the exchanger bypassed (the original exchanger train had no bypasses on either shellside or tubeside).

Background

This exchanger is 1 of 3 combined feed exchanger shells in series and is the last exchanger before the fired charge heater on the feed side and the first exchanger after the tail reactor on the reactor effluent side. It is a TEMA type BEU exchanger with 1 shellside and 2 tubeside passes (282 off U tubes with strength-welded tube to tubesheet joints) and had been in service for 23 years. The tubeside fluid is reactor effluent which enters at a pressure of approximately 25.5 barg (370 psig) and a temperature in the range 480 °C (896 °F) at start of run to 530 °C (986 °F) at end of run.

Visual inspection of the failed exchanger revealed that the channel head (“stationary head” or “bonnet”) flange had been out of alignment by approximately 3 mm. Metallurgical analysis revealed that the failure mechanism was brittle fracture. The channel head is fabricated from 40 mm thick 2.25 Cr/1.0 Mo plate (ASTM A387 Gr. 22 Cl. 2) and the main flange is fabricated from 195 mm thick 1.25 Cr/0.5 Mo (ASTM A182 Gr. F11). The exchanger was specified with a tubeside design pressure of 32.8 barg (475 psig) and a minimum acceptable water temperature for hydrotest of 6 °C (43 °F). The hydrotest water temperature at the time of this incident was approximately 20 °C (68 °F).

Causes

The immediate cause of the channel head failure was brittle fracture due to temper embrittlement. Uneven bolt torque and flange misalignment were contributing factors. Critical factors included the age, composition and thermal history of the steel (susceptibility to temper embrittlement) and inappropriate selection of the hydrotest pressure (full hydrotest pressure not required if only verifying tube-to-tubesheet joint integrity). The root cause was inadequate job knowledge.

Lessons

Temper embrittlement causes a loss of toughness in low alloy Cr-Mo steels after extended exposure to temperatures in the range 327 - 593 °C (620 - 1100 °F). The effect is most pronounced in the range 427 - 510 °C (800 - 950 °F) and most common in 2.25 Cr/1.0 Mo steels. The loss of toughness is not evident at operating temperature and only affects the material when exposed to relatively low temperatures (eg. startup and shutdown). It can cause catastrophic brittle fracture. Temper embrittlement is caused by segregation of tramp elements and alloying elements along grain boundaries in the steel. Susceptibility to temper embrittlement is mainly determined by the presence of alloying elements (Mn and Si) and tramp elements (P, Sn, Sb and As). Temper embrittlement of the steel cannot be prevented if it contains critical levels of these elements and has had extended exposure to temperatures in the embrittling range.

Temper embrittlement cannot by detected by normal non-destructive testing (NDT) inspection techniques so all low alloy Cr-Mo equipment should be assumed to be at risk of brittle fracture through temper embrittlement until the ductile-to-brittle transition temperature has been exceeded. Internal pressures in susceptible equipment should not be allowed to exceed 25% of design pressure until the metal temperature exceeds the Minimum Pressurisation Temperature (MPT) for that equipment (MPT is a function of metal composition and service history).