Failure analysis of an ethylene cracking heater finned tube

Here's what caused the leak and the steps taken to prevent future leaks

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During the hydrotest as per the annual health check plan of this furnace, water leakage from the convection zone was noticed and further investigation, by opening the convection box cover at different locations, showed that a 4-in. Ø finned tube of the first-pass coil of the convection zone was leaking.

Appearance/morphology of damage. An elliptical shaped 12-mm × 7-mm puncture was noticed toward the north side of the convection zone at the tube entry point in the convection zone.

Erosion and erosion corrosion are characterized by a localized loss in thickness in the form of pits, grooves, gullies, waves, rounded holes and valleys. This loss often exhibits a directional pattern (Fig. 1).

TABLE 1. Operating data

Operating parameters	Cracking mode		
	Ethane	Propane	Decoking
Operating pressure, kg/cm²G	6.4, 6.5, 6.6	6.4, 6.5, 6.6	Steam was stagnant (not live) during the decoking cycle
Operating temperature, °C	150	150	150
Service	HC + DMDS	HC + DMDS	Steam + hydrazine + condensate + hot air
pH of fluid handled			9.0, 9.3
Production cycle	40–50 days	40–50 days	
Decoking cycle			35–45 hr
MOC	A 106 Gr. B		

Process details.

Function of HC preheater-1 furnace. Hydrocarbon preheater-1's function is to preheat the HC (i.e., ethane/propane) from 65°C to 125°C to 145°C through furnace flue gases. Preheater-1 contains HC with DMDS catalyst in normal furnace cracking operation. During the decoking cycle, the HC feed control valve remains closed whereas decoking steam and hot air are introduced through preheater-2. From preheater-2 onward, steam is live, i.e., circulating through preheater-2, the economizer, the superheater and furnace area, and the decoking network piping including the decoking pot. The only area where the steam is not live, i.e., the steam is stagnant, is preheater-1 (Fig. 2). The operating data are shown in Table 1.

Probable reasons of failure. Tube failure may have occurred due to any one or a combination of the following probable reasons:

- Faulty material of construction (MOC)
- Corrosion
- Erosion corrosion
- Upset in process.

Visual inspection, NDT and metallography of the failed fin tube were carried out to find the root cause of the failure. Three small pieces were cut at different locations of this finned tube for study and visual inspection.

At tube failed location:

- As mentioned, an elliptical shaped 12-mm × 7-mm puncture was noticed toward the north side of the convection zone at the tube entry point in the convection zone.
- Liquid stagnation marks were noticed between the 5 o'clock and 7 o'clock positions of the finned tube.
- Severe roughening and pitting were noticed at the 6 o'clock position on the internal surface of the tube near the puncture area, which may be indicative of the presence of moisture from steam condensate, O_2, sulfur (40–50 ppm) from DMDS, CO_2 from HC, and NH_3 from hydrazine, i.e., a corrosive environment.
- In the vicinity of the punctured area the OD of the fins was found eaten away.
- A black sticky process deposit was noticed between the 5 o'clock and 7 o'clock positions.

At other locations (three samples of 6 in. were cut):

TABLE 2. Chemical analysis results

Elements	$C_{max.}$	$Si_{min.}$	Mn	$P_{max.}$	$S_{max.}$	$Ni_{max.}$	$Cr_{max.}$	$Mo_{max.}$	$Cu_{max.}$	$V_{max.}$
As per A 106 Gr. B	0.3	0.1	0.29 – 1.06	0.035	0.035	0.4	0.4	0.15	0.4	0.08
Failed sample	0.225	0.216	0.582	0.028	0.006	0.01	0.034	0.017	0.016	0.014

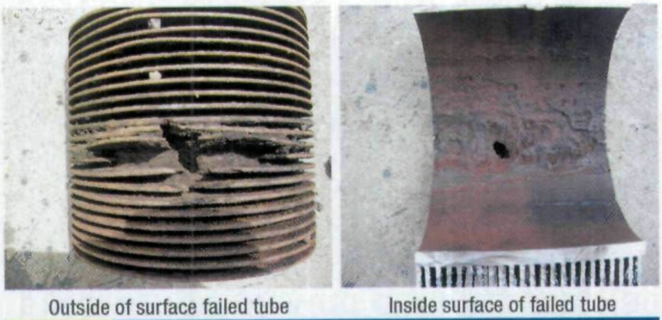

FIG. 1 Erosion and erosion corrosion are characterized by a localized loss in thickness.

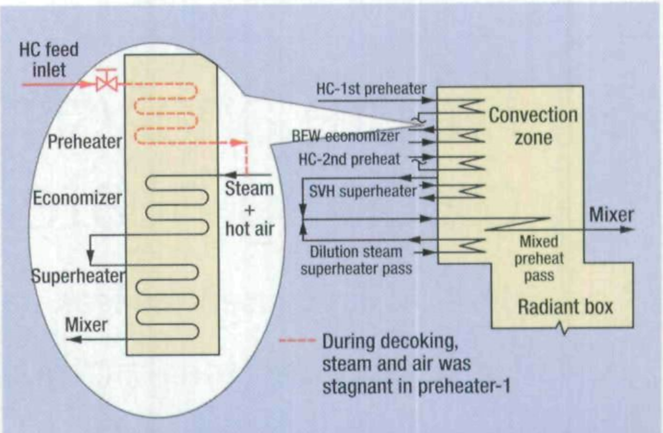

FIG. 2 The only area where the steam is not live is in preheater- 1.

• Liquid stagnation marks were noticed between the 5 o'clock and 7 o'clock positions of the finned tube.

• Roughening and pitting were noticed at the 6 o'clock position on the tube internal surface. However, the extent of corrosion is less in these samples compared to the failed portion.

The failed sample was chemically analyzed and the results are shown in Table 2.

Hardness of the cross-section of the failed samples was taken and found in the range of 82–85 HRB. Hardness values are normal for this MOC.

The microstructure of the failed finned tube cross section was examined and found to be normal, i.e., ferrite and pearlite (Fig. 3). Approximate grain size was 7–8, meaning a fine-grained CS microstructure is normal for CS–A 106 Gr. B.

Root-cause analysis.

• The chemical, hardness and metallographic studies confirmed that the MOC of the tube is A 106 Gr. B, which is the correct MOC. No abnormality was noticed in the finned tube metallurgy. Tube failure due to faulty MOC is ruled out.

• Stagnation of steam and condensate during the heater decoking cycle increases the corrosivity of the environment, reduces stability of the protective surface films and increases susceptibility to metal loss. Metal may be removed from the surface as dissolved iron or as solid corrosion products, which are mechanically swept from the finned tube surface. The size, shape, density and hardness of the impacting medium also affect the metal loss rate from the finned tube.

• Factors that contribute to an increase in corrosivity of the environment, such as temperature and pH, can increase susceptibility to metal loss.

• Erosion can be caused by gas-borne catalyst particles or particles carried by a liquid such as a slurry (mixture of HC deposits, steam and condensate). This form of damage occurs as a result of catalyst (DMDS) movement in the FCC reactor/regenerator.

• Liquid level effects—Crevice corrosion often occurs underneath solid substance deposits that sometimes collect just above the liquid level on a metal part that is partly immersed in an electrolyte. The deposit usually remains moist or intermittently moist and dry.

• CO_2 corrosion results when CO_2 dissolved in water forms carbonic acid (H_2CO_3). The acid may lower the pH and a sufficient quantity may promote general corrosion and/or pitting corrosion of carbon steel.

• Sulfur from DMDS catalyst—At a low enough temperature (about 138°C), the gas and water vapor will condense to form sulfurous and sulfuric acid, depend-

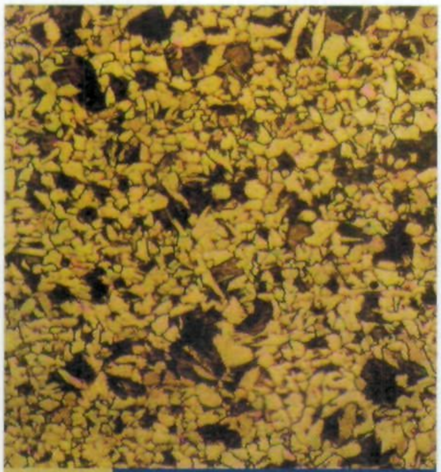

FIG. 3 The microstructure of the failed finned tube cross-section was examined and found to be normal.

ing upon the concentration of sulfur trioxide, which can lead to severe corrosion.

• Localized flow can create a deep circumferential groove called condensate grooving if the condensate contains a high level of NH_3, O_2 and air.

• The earlier production cycle was quite short, i.e., 25 days or approximately half of the present situation. This means that the decoking cycle of 35–45 hr repeated twice earlier over the present situation. These tubes are subjected to two different service conditions, i.e., HC during normal operation and stagnate steam and condensate during decoking cycles. This stagnation condition of steam and condensate leads to corrosion and subsequent tube failure.

• Corrosion is noticed throughout the tube internal surface but at the failed location it is very high. This may be due to initial tube surface roughness or excessive accumulation of stagnate condensate at that location.

The metal area where the liquid level fluctuates or the liquid agitates that is intermittently wetted is called the splash zone. Corrosion occurring in this area is called splash-zone corrosion.

• General metal loss is defined as relatively uniform thinning over a significant area of the equipment. Corrosion and erosion are never totally uniform; a rule of thumb is that, if the metal loss rate among different points in an area varies by a factor of four or less, then damage is considered general.

Stagnant steam and condensate during the heater decoking cycle increased the corrosivity of the environment and led to failure of the HC preheat line finned tube in the convection zone (Fig. 4).

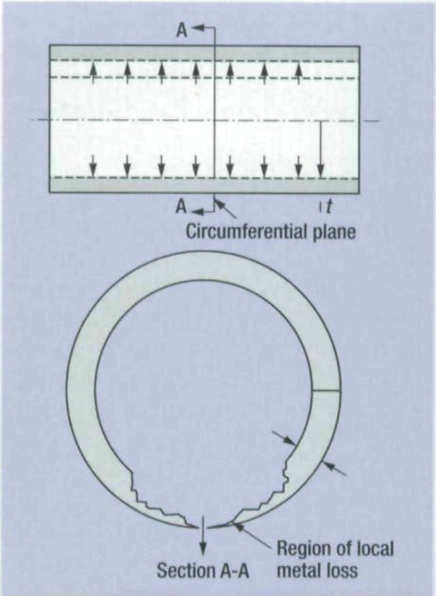

FIG. 4 Local metal loss was evident in the internal bottom portion of the tube.

Recommendations.

• Stagnation of steam and condensate during the heater decoking cycle is avoided by providing a line from the HC control valve low drain point to the decoke pot so that during furnace decoking, positive flow through hydrocarbon preheater 1 can be ensured.

• A tube of the other heater similar to preheater-1 should be removed for the inspection to assess its health.

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