Solving a Steam Generating Tube Failure

A case history of a tube failure in the primary reformer furnace of a 600-ton/day ammonia unit, telling how the problem was analyzed, repairs were made, and steps taken to prevent a recurrence.

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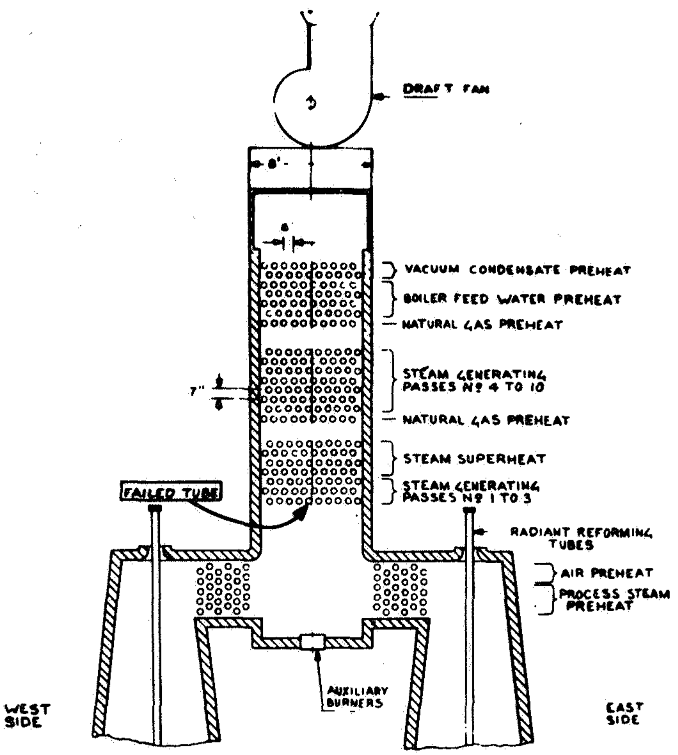

Figure 1. Reformer furnace convection section, cross-sectional view.

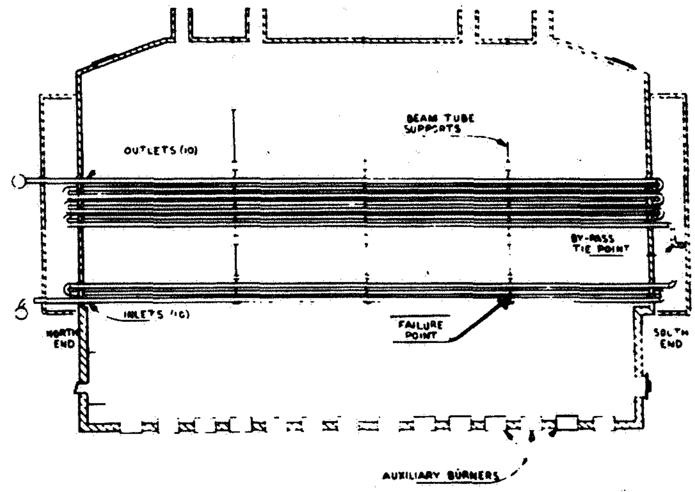

Figure 2. Reformer furnace convection section, side-sectional view, showing auxiliary burners and steam generating tubes.

Esso Chemical Canada's 600-ton/day ammonia unit near Edmonton, Alberta, Canada, has a Foster-Wheeler primary reformer furnace. The reformer consists of two radiant cells (see Figures 1 and 2). Each cell contains 80 HK-40 tubes and is fired by 56 burners located in four "terraces" at two levels. On top of these 53 ft. high radiant cells lies a convection section 8 ft. wide, 24 ft. high and 46 ft. long. The flue gas from each radiant cell passes through the arch area, where process steam and air heating oils are located, and then flows into the convection section. The combined flue gas streams then flow upwards towards the top outlet, where two induced draft fans are installed.

The convection section of the furnace, which recovers heat from the radiant section, contains 22 levels of tubes. Each level consists of 10 parallel tubes. The top two rows heat the vacuum condensate; rows 3 to 6 contain boiler feed water; gas preheating is accomplished in rows 7 and 15; steam superheating occurs through levels 16 to 19; and steam is generated in rows 8 to 14 and 20 to 22. Failure occurred in row 22, which is the first pass of the steam generating tubes.

The 22 rows of tubes are held in position by three 25-20 HK cast alloy tube supports. The tube supports are 7-in. I-beams with 5-in. diameter holes drilled through the web.

Fourteen auxiliary burners are located at the bottom of the convection section and provide 71 million Btu./hr. The total heat requirement to the 220 tubes in the convection section is 134 million Btu/hr.

Boiler feed water from the secondary reformer waste heat boiler is circulated through the 10 steam generating tube passes by a pump at 600 lb./sq. in. gauge. Steam is generated at a design rate of 82,000 lb./hr. and a vaporization rate of 10% (see Figure 3). The first tube pass in row 22 is located 9 ft. above 14 auxiliary burners. The flue gas temperature at this point ranges between 1700 to 1750°F.

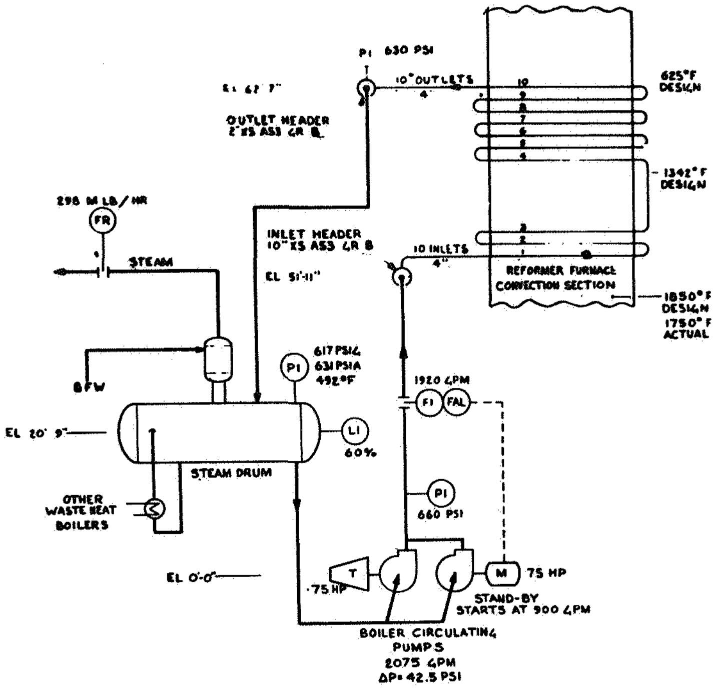

Figure 3. Steam generation loop.

The steam generating tubes are 4.5 in. O.D. and 0.237 in. nominal thickness, schedule 40, carbon steel, ASTM A106-67 grade B pipe. A length of 46 ft. is in contact with the direct firing from the burners. The tube material was selected on the basis of 650°F. tube metal temperature because design internal stream temperature is 492°F., the equivalent of 600 lb./sq. in. gauge saturated steam pressure.

The furnace was started in Spring, 1969. The convection section at the time of the steam generating tube failure had 23,500 hr. of problem free operation.

Failure was a tube rupture

On December 2, 1972, a leak was detected on level 22, the first pass of the steam generating tubes.

The unit was shut down on December 6, cooled and inspected on December 7. Tube failure had occurred on the fifth tube of the first pass. A hole approximately 0.9 in. long and 0.2 in. wide was found at the 12 o'clock position directly inside the south tube support. The inside of the failed tube was generally thinned for a radius of approximately 1 in. around the rupture point (see Figure 4).

Ultrasonic wall thickness readings of all 10 branches were taken. It was revealed that the tubes located in the center of the firebox (Nos. 4, 5 and 6 from the west) were extremely thinned at the top. In the case of No. 6 tube, the upper wall thickness was only 0.087 in. which was 37% of the original 0.237 in. thickness. The bottom side of the tubes showed no wear at all. Tube Nos. 3, 7 and 8 had 63% of the original wall thickness (Figure 5).

Also noticed was a deposit of iron oxide and boiler chemicals in the top part of the tube. The deposits formed two horizontal lines starting approximately 15 ft. from the tube inlet and decreasing in elevation. This deposit indicated the boiler feed water level inside the tube and confirmed the existence of a vapor and liquid phase. Analysis of the deposit was typical of those of boiler feedwater chemicals, as seen in Table 1.

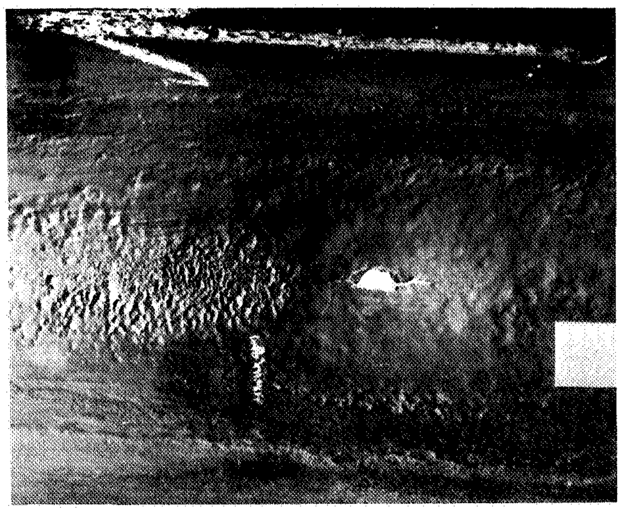

Figure 4. Inside surface of failed tube.

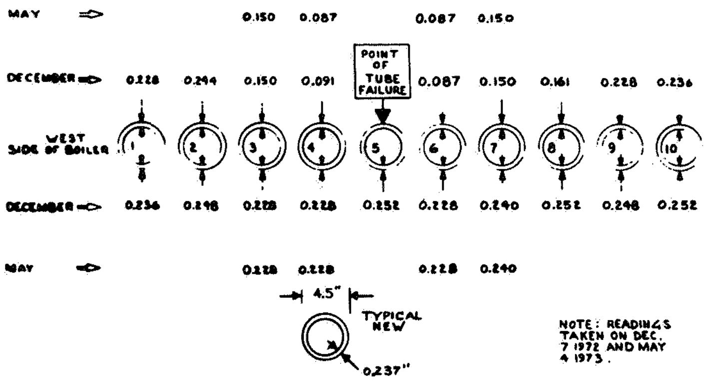

Figure 5. Wall thickness measurements of steam generating tubes.

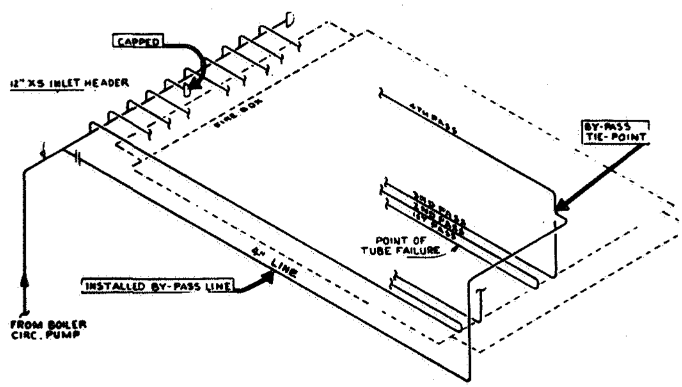

Figure 6. Temporary installation of by-pass line for failed steam generating tube.

Table 1. Analysis of deposit

Fe_2O_3	32%
PO_4	1.2%
Na	0.6%
HCO_3^-, $CO_3^=$	Nil
Cr^{+6}, SO_4	Nil
Cl^-	Nil
Ignition Loss	–
Insolubles in aqua regia	61.8%
Insolubles in H_2O	95.0%

Downtime minimized for repairs

Several causes for the failure were suspected.

1. The radiation of heat from the 7-in. wide I-beam tube support which could have resulted in heat concentration at the point of failure.

2. Accumulation of boiler chemicals, that is, caustic at the point of failure.

3. Low boiler feed water circulation rates which resulted in a liquid and vapor separation.

4. High tube metal temperatures at center tubes due to location of burners.

To minimize the downtime, spool pieces were fabricated before shutting the furnace down.

The outlet from the header to the failed pipe was cut and capped. A bypass pipe outside the firebox was installed and connected to the inlet of the fourth pass (Figure 6). The three cut tubes remained in the firebox to reduce downtime.

For the remaining nine tubes in the firebox, strips of felted asbestos insulating material, 1/8 in. thick, were placed around the top half of the tubes in the area where the tubes pass through the holes in the pipe support (Figure 7). This was an attempt to minimize heat transfer from the wide flanged I-beam to the tube.

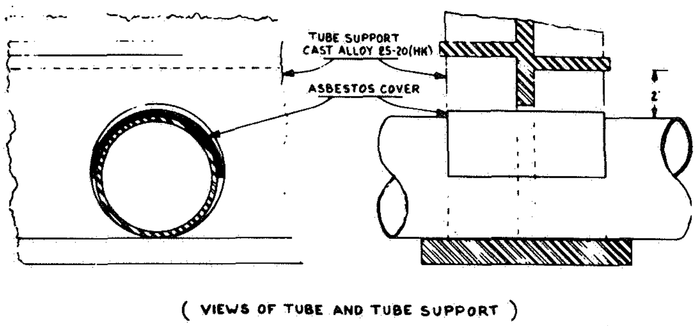

Figure 7. Placing insulating material around the top half of the tubes in the pipe supports.

After startup, the firing of the auxiliary burners was reduced to 1700°F. This situation was rather costly because the lower firing rates resulted in lower steam superheat temperatures to the power steam of the major turbines as the steam superheat tubes are also in this convection section.

In addition, the standby boiler feed water circulating pump was placed into service resulting in a total flow of 2,400 gal./min., through the steam generating tubes, an increase of 25% from the previous 1,920 gal./min. prior to shutdown.

Failure shown caused by caustic attack

The close visual and metallographic observations of the failed tube section indicated that failure occurred due to concentrated caustic attack where vapor phase existed. The tube was cut cross-sectionally through the pitted area and the type of pitting shown in Figure 8 was found. This pitting, characterized by severe undercutting and general roundness is believed to be typical of that produced by concentrated (up to 40%) caustic solutions.

Figure 8. Pitting on internal surface of the steam generation coil. Magnification 100X, unetched.

The parallel grooves near the top of the inside of the pipe indicated that at this position in the tube, the water and steam existed as separate layers, with water filling most of the pipe and a small steam layer existing at the top. Turbulence in the stream could periodically cause some of the liquid to splash and contact the hotter metal in the steam zone. The water-caustic solution could then concentrate and cause corrosion of the type shown in Figure 8. The cycle of splashing, concentration and corrosion was repeated until failure occurred. Expert's* opinion about overheating was that it may have localized the corrosion to some extent but was not an actual cause of the failure.

In the boiler feed water quality, no unusual deviations were found. Routine boiler feed water analysis had been done twice a day and the typical range had been TDS 350-450 ppm, SiO_2 5-15 ppm, PO_4 20-30 ppm, and alkalinity of 180-220 ppm.

The vapor liquid separation in the tube was studied in great detail. Initially, the flow condition in the tube as steam generation progresses was checked by conventional methods. Observation of the failed section seemed to indicate that plug flow and most likely, stratified flow regimes existed in the tubes. However, this could not be verified by the calculation based on existent flow rates and degree of vaporization. The classical calculations clearly indicated that the estimated flow regimes in the steam generating tubes were bubble flow, annular flow and spray flow as vaporization progressed.

The laboratory research by Esso Research and Engineering established that in the bubble flow regime two phases actually existed; dispersed bubble flow, and coalesced bubble flow which occurs at about 7-9% vapor content (see Figure 9).

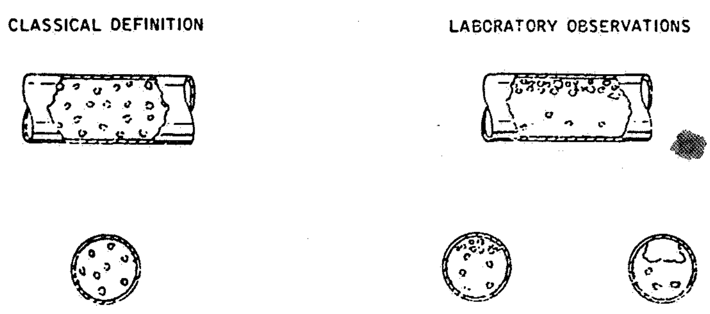

Figure 9. Bubble flow regimes in horizontal flow.

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To avoid bubble coalescence, the following steps could be undertaken:

1. Increase circulation rate from 1,900 to 19,000 gal./min.

2. Install orifice plates of varying sizes on the first ten tubes with resultant increasing pressure differential of 5 to 7 lb./sq. in.

Neither step, however, appeared to be a practical solution.

The replacement of present tube material with 1.5 Cr., 0.5 Mo. alloy was also considered to improve abrasion and corrosion resistance.

Boiler feedwater treatment most promising solution

The most attractive and promising solution to postpone failure was in the treatment of boiler feed water. As the primary cause of the steam generating tube failure was caustic attack, it became evident to reduce caustic concentration to a minimum. Co-ordinated phosphate treatment of boiler feed water was initiated. Controls were set up to maintain the pH of the boiler feed water between 9.8 to 10.3, and the Na/PO_4 ratio between 2.4 to 2.8.

On May 4, 1973, after five months' operation with the uneasy feeling that the steam generation tube which had only 0.087 in. thickness may fail at any moment, an inspection was made utilizing a shutdown occasion caused by some other reason. It was found that practically no further deterioration happened as indicated by the second set of numbers on Figure 5. The bypassed tubes left in the firebox without flow were, of course, burnt out. These dead tubes were removed, the insulation sheet at the tube support holes was readjusted and the furnace went back into operation. During the September turnaround, all 30 steam generating tubes were to be replaced with original specified carbon steel material.

Summary

Steam generating tube failure was caused by caustic concentration at a point where coalesced bubble flow caused the dry condition to exist at the 12 o'clock position of the tube. The elimination of a coalesced bubble flow regime is impractical. A change-over of treatment of boiler feed water from caustic to co-ordinated phosphate control where exact limits must be maintained is expected to either eliminate failure or greatly extend tube life. #

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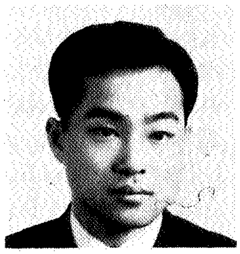

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